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CONTENTS

Introduction	1
The Federal Beat	3
The Industry Scene	9
Technology Development	19
State and Local	41
International	47
Technology Transfer	55
Other Information Sources	62
Power Plant Tables	63
Directory	71

COVER PHOTO:

Geothermal power plant under construction by CalEnergy Company, Inc., at Mahanagdong, Philippines. This 164 MWe plant, expected to come on line in mid-1997, is one of many new large international geothermal development projects of U.S. firms.

INTRODUCTION

The near-term challenges of the U.S. geothermal industry and its long-range potential are dominant themes in this issue of the U.S. Department of Energy (DOE) Geothermal Progress Monitor which summarizes calendar-year 1996 events in geothermal development. Competition is seen as an antidote to current problems and a cornerstone of the future. Thus, industry's cost-cutting strategies needed to increase the competitiveness of geothermal energy in world markets are examined.

For example, a major challenge facing the U.S. industry today is that the sales contracts of independent producers have reached, or soon will, the critical stage when the prices utilities must pay them drop precipitously, aptly called "the cliff." However, Thomas R. Mason, President and CEO of CalEnergy told the DOE 1996 Geothermal Program Review XIV audience that while some of his company's plants have "gone over the cliff, the world is not coming to an end." With the imposition of severe cost-cutting strategies, he said, "these plants remain profitable...although they have to be run with fewer people and less availability."

Unocal's Darcel L. Hulse stressed the importance to increased competition of new technologies "to map the productive parts of hydrothermal systems and to increase the efficiency and reduce the cost of drilling in volcanic environments." Since "there is no positive cash flow or return on investment until a project is completed and the high cost of exploration and drilling have occurred," he said. "One dollar saved at the start of a project is worth two in the last stages of the project."

The government-industry R&D response to the need for improvements in these two stages of development are evident in the TECHNOLOGY DEVELOPMENT section. Enhancements to the general purpose fluid and heat flow simulator, TOUGH2, are expected to provide a more accurate and comprehensive description of reservoir processes. The availability of reservoir simulators that use curved interface thermodynamics is also announced.

Analysis of core from The Geysers field in California and the Tiwi field in the Philippines has demonstrated that, contrary to earlier conclusions, permeability is controlled by high-angle fractures, a significant step in the difficult process of determining the relative productivity of fractures. Other 1996 reservoir studies reported in the TECHNOLOGY DEVELOPMENT section have yielded new information on The Geysers and assessed the potential role of microearthquakes as a reservoir management tool.

The emphasis on improved and new, advanced drilling technologies as reflected in this issue of the Geothermal Progress Monitor (GPM) has never been stronger. An evaluation of advanced drilling concepts has been completed, concluding that significant reductions in drilling costs can only occur by changing the nature of the system or by increasing the rate of penetration. Successful tests of innovative drilling technologies -- e.g., drillable straddle packer and core-tube latch detector -- are announced, and enhancements in others -- rolling float meter and a pressure-temperature logging tool -- are described. Major emphasis has

been placed on advanced drilling technologies by two federal programs. The National Advanced Drilling and Excavation Technologies (NADET) Institute announced R&D grants for seven projects in geothermal drilling research. DOE's Small Business Innovative Research (SBIR) Program selected advanced drilling systems as one of its focus areas for 1996, awarding nine R&D contracts.

The TECHNOLOGY DEVELOPMENT section also reports the successful commercial demonstration of supersaturated turbine expansions in binary cycle operations. Confirming the results of earlier studies, a binary unit operating with metastable expansions consistently produced more power from the same brine flow than its sister unit. A full-scale test of another promising conversion technology, the Biphase turbine, will get underway at the Cerro Prieto field in Mexico in 1997.

The STATE AND LOCAL section reports that the state of California is again taking the lead in legislative and regulatory actions that enhance the future of renewable energy and allow independent power producers to compete with utilities on an equal basis. Reports from New York indicate that it is the first eastern state to conduct a major assessment of its geothermal resources and to estimate the costs of using them for power generation.

As might be expected, the INTERNATIONAL section of GPM becomes more prominent with each issue. The overseas activities of U.S. companies continue to expand, and more and more countries are actively investigating their geothermal potential. Activities in areas of the world ranging from the Pacific Islands to Central and South America are reported in this issue.

DOE's Office of Scientific and Technical Information at the Oak Ridge Laboratory is replacing its bimonthly geothermal

abstracts publication -- "Geothermal Technology" or GET -- with a new service to provide electronic access to the abstracts through a Current Awareness Publication (CAP). You can notify OSTI of your interest in receiving, free-of-charge, listings of the titles from CAP during the preceding two months.

Allan Jelacic, director of the Department's Office of Geothermal Technologies, acknowledged the industry's challenges which lie ahead. He observed, "The best way we can help industry meet these challenges is through new technologies." To this end, he noted that the goals of the geothermal R&D program have been incorporated into the OGT mission statement:

"By working in partnership with industry and other stakeholders, we will develop and implement a balanced program of research and development to provide technology that will enable the geothermal industry to meet U.S. and world energy needs."

Expressing pride that approximately half of OGT's research and development program budget involves cost-shared projects with industry, Dr. Jelacic concluded that: "The high degree of government-industry cooperation indicates that government money is being put to good use and furthering technology in the near term."

THE FEDERAL BEAT

CONVERGING TRENDS POINT TO GREATER WORLDWIDE USE OF RENEWABLE ENERGY, WITH KEY ROLE FOR GEOTHERMAL

Noting that certain factors are coming together to shape our energy future, Dr. Allan Hoffman, Acting Deputy Assistant Secretary of DOE's Office of Utility Technologies, predicted that converging trends will inevitably lead to greater use of renewable energy in the future.

"I do not see any alternative ... if we are going to move toward a sustainable society," he told the opening session of DOE's Geothermal Program Review XIV held in April 1996 in Berkeley, California. In his keynote remarks addressing the theme, "Keeping Geothermal Energy Competitive in Foreign and Domestic Markets," Hoffman expressed his confidence that geothermal energy will play a key role in both.

A major factor affecting the future shape of the world's energy systems, he said, is the "growing energy demand, particularly in developing countries, where most of the demand will come from over the next several decades." The World Bank, he added, has estimated that over the next three to four decades demand for new electricity capacity in those countries alone will be on the order of five million megawatts. If the average cost of the new capacity is about \$1,500 per kilowatt, the total would be about \$7 to \$8 trillion, independent of the infrastructure that goes

with it. With these numbers, Hoffman observed, "you begin to understand why there is such intense international competition for these emerging markets."

He said he had noted "a real movement toward increased business interest" in renewable technologies. "The most exciting thing to me at a recent SOLTECH meeting," a gathering of the solar industry, he said, "was the fact that the utilities are finally beginning to see a way to make money using renewable energy. I think there is a sea change in many ways, in the understanding that renewable energy can be big business and high profits, at least in the longer term."

Other factors he enumerated that are coming together to shape our energy future include:

- Increased environmental concern. Plans are already in development for the post-2000 effort to reduce ambient concentration of carbon dioxide.
- Increased population. For example, China and India will soon embrace half of the world's population. Since both are major coal producers and users, alternatives need to be offered.
- Social issues. For example, there is no infrastructure to accommodate nuclear power in many developing countries.
- According to the chairman and CEO of Shell UK Ltd., "while fossil fuel supplies will continue to increase between now and the next century, they will peak out at some point and begin to diminish,

possibly around 2030, at which time renewables will become the dominant energy source."

- For the U.S., a whole range of issues associated with energy security will have to be addressed since most of the world's oil reserves lie in the Persian Gulf.
- According to polls, the American public strongly supports renewable energy.

"Where does geothermal fit in all this?" Dr. Hoffman asked. It is one of the two base load renewable technologies, and there is a tremendous geothermal resource base around the world, both in terms of hydrothermal resources and hot dry rock.

"Geothermal, if developed properly, can be an environmentally attractive technology. It does not have to emit hydrogen sulfide," he said, "and that message should be conveyed to those who think otherwise." Significant technical advances have been made over recent years, with a tripling of geothermal capacity since 1980. The cost of resource discovery, power plants, and peripheral equipment has reduced the levelized cost of power to 5¢/kWh, although, further reduction is needed to compete with natural gas prices of 2-3¢/kWh. In addition, he said, "geothermal is a hedge against price volatility." Most notably, the U.S. geothermal industry has performed extremely well in successfully installing overseas projects, demonstrating its ability to compete in international markets.

He also noted that geothermal heat pumps (GHPs) are a very attractive option since 1) they probably give electricity customers the lowest-cost heating and cooling system available on a life-cycle basis, and 2) they help utilities reduce peak loads in summer and winter. The key barrier to increased use of most residential GHPs is the higher front-end costs. However, we have strong

pockets of success in both residential and commercial GHPs which we need to transfer broadly nationwide. This is the major focus of the utility sector's Climate Challenge Program, a voluntary initiative in which DOE is participating.

Dr. Hoffman outlined how he expected the DOE geothermal research program to evolve to help industry meet the new challenges of the energy world:

- A continued effort to reduce costs
- Continued assistance in identifying resources around the world
- Development of smaller power plants through demonstration projects, and
- Integration of its hot dry rock program into the mainstream geothermal program to "learn a lot about ... this immense and ubiquitous resource ... by working in traditional geothermal areas."

Hoffman concluded by saying "we are going to be moving inexorably toward increasing reliance on renewable energy. ... Today, we are in the early stages of a long-term transition. It is going to be chaotic and difficult, but we are beginning to move in that direction."

PROGRAM DIRECTOR ADDRESSES HOW RESEARCH WILL HELP GEOTHERMAL INDUSTRY MEET NEAR-TERM CHALLENGES

In his opening remarks at Program Review XIV, Dr. Allan Jelacic, Director of DOE's Office of Geothermal Technologies (OGT), expressed confidence that the OGT program would provide the industry with

many new and useful tools that will enable it to meet the challenges of the next three to five years. "These are troubling times for the Government," Jelacic said, citing reorganizations and downsizing, "but they are not nearly as troubling as the challenges that face the geothermal industry today."

Challenges he discussed include:

- Weak domestic markets for new electric power in the west, especially in California
- Price competition caused by cheaper and more abundant natural gas
- A threat to repeal some of the advantages offered to the non-utility independent power producers (IPPs) by the 1978 Public Utilities Regulatory Policy Act (PURPA)
- The restructuring of the utility industry, geothermal's primary customers
- The ISO-4 "cliff" in California, when prices received by IPPs drop precipitously after the initial 10-year contract period. (The Interim Standard Offer No.4 contracts were developed by the California Public Utilities Commission to encourage growth of IPPs by providing a relatively high price for electricity over the initial 10-year period. The contracts of a number of IPPs have reached or will soon reach this critical milestone.)
- The move overseas undertaken by the industry into new, untried, and potentially unstable markets.

Jelacic said, "the best way we can help industry meet these challenges is through new technology." To this end, he noted that the goals of the geothermal R&D program have been incorporated in the OGT mission statement, which states:

"By working in partnership with industry and other stakeholders, we shall develop and implement a balanced program of research and development to provide technology that will enable the geothermal industry to meet the U.S. and world energy needs."

He indicated that a balance in the R&D program was achieved by restructuring the program in 1992, which permitted the close alignment of the four phases of geothermal development. These include finding a resource through exploration; accessing the resource through drilling; managing the resource through reservoir technology; and putting the resource to use through conversion technology.

The R&D program has also benefitted from increased industry participation in R&D program planning. Dr. Jelacic traced the origins of this change to a May 1995 meeting of DOE Secretary Hazel O'Leary with industry representatives at the World Geothermal Congress in Florence, Italy. She urged closer cooperation of the DOE geothermal program with "our industry and our customers."

"We began planning with industry for a stronger partnership within an hour of that meeting," Jelacic said. He noted that since then, workshops where industry advises the DOE geothermal program on improving thrusts for research have been held much more frequently and regularly. (See GPM Issue No. 17.)

In addition, he said, "Many of our research thrusts, if not most, have a fair amount of industry cost-shared involvement. Approximately half of our current budget is in cost-shared projects with industry, and we are proud of that fact."

Dr. Jelacic indicated that additional opportunities are coming up for partnering and cost-sharing. These include a recent

solicitation for development of advanced and/or revolutionary drilling technologies. He suggested that the highly successful industry-coupled drilling program of the 1970s and early 1980s could be reinstituted if there is sufficient interest. He further reminded participants that proposals are welcome in the areas of reservoir technology, supersaturated turbine expansions, and newly-developed coating materials. The new hot dry rock program will also have a sizeable industry component.

Jelacic concluded by saying "the high degree of government and industry cooperation indicates that government money is being put to good use and furthering technology in the short-term."

NEW CHARTER SET FOR GEOTHERMAL POWER ORGANIZATION

The objective of the Geothermal Power Organization (GPO) is to identify and develop industry-driven research projects that serve to advance geothermal energy conversion technology. Supported by DOE, the GPO began in 1993 as an advisory group of geothermal industry professionals working on energy conversion technologies and equipment. Its formation involved the consolidation of the functions of the former Energy Conversion Panel (ECP) and the Technical Advisory Group (TAG). Since its inception, the GPO has provided an effective forum to discuss the research needs of the industry and to promote geothermal energy as a cost-effective fuel for generating electricity. It has promoted an active exchange of ideas providing industry insight and guidance to the DOE geothermal energy conversion program.

As a result of the members' active involvement at the biannual GPO meetings,

a fundamental change in the structure of the organization was instituted to enable it to pursue cost-shared research and development with DOE. Over the last three years, efforts had centered on investigating and establishing cost-sharing mechanisms, and then implementing the one that met members' and DOE's standards. A new Memorandum of Understanding between the DOE Golden Field Office and the GPO will now permit a new, more structured organizational charter that facilitates cost-shared initiatives.

DOD'S LARGEST SHARED-ENERGY SAVINGS PROJECT COMPLETED AHEAD OF SCHEDULE

As part of the Department of Defense's Strategic and Environmental Resource and Development Program (SERDP), the Army's Corps of Engineers awarded a shared-energy savings contract to Co-Energy Group (CEG) of Santa Monica, California, in January 1994. The contract required replacing heating and air conditioning units in 4,000 homes at the family housing area at Fort Polk, Louisiana, with new closed-loop geothermal heat pumps (GHPs), making the project the largest GHP project in the world. Co-Energy was given three years to install the GHPs, but to improve its cash flow, the company completed the installation in just a little over one year.

Statistically valid before and after data indicates: annual saving of 26 million kWh (33 percent savings); reduced peak load of 6.8 MW (40 percent reduction); and improved whole house load factor from .54 to .61. The GHPs accounted for more than two-thirds of the savings. CEG was also contracted to insulate attics and water heaters, add weather stripping, retrofit interior and exterior lighting, and take other steps designed to reduce energy requirements.

In addition to furnishing all the necessary equipment, materials, and labor to fulfill the contract, the company will maintain the GHPs for the next 20 years. This arrangement will produce 30 percent savings in maintenance costs. The government will also save an estimated \$44 million (in 1994 dollars) in lower utility bills. The total energy savings (including interest) will be over \$102.5 million.

GEOHERMAL HEAT PUMP CONSORTIUM FUNDS TWELVE UTILITY PROGRAMS

The Geothermal Heat Pump Consortium (GHPC) held its second annual meeting in Washington, D.C., on February 7-9, 1996. Christine Ervin, DOE Assistant Secretary for Energy Efficiency and Renewable Energy, and Mary Nichols, EPA Assistant Administrator for Air and Radiation, awarded the GHPC grants to eight utilities. Grant recipients include: Plumas-Sierra Rural Electric Cooperative, Northeast Utilities, Kansas City Power & Light, Minnesota Power, Duke Power, Pennsylvania Power and Light, Virginia Power, and Detroit Edison.

Duke Power, the first investor-owned utility to instigate a "pilot" GHP program, plans to persuade regional and national homebuilders to build "all geothermal" subdivisions. Plumas-Sierra Rural Electric Cooperative in California plans retrofits of homes and condos. Virginia Power will focus on heating and cooling 71,000,000 square feet in 7,770 state-owned buildings. Minnesota Power will work with new gas stations to connect the HVAC, freezer, refrigeration, and icemaker systems to the GHP ground heat exchanger. The GHP system will also heat the car wash and ramps to allow year-round operation. Southern Company and Oglethorpe signed

major contracts later in the year to focus on residential and commercial GHP programs. Pacific Gas & Electric, Jersey Central Power & Light, Atlantic Electric, and Potomac Electric Power Company were negotiating with the GHPC in late 1996.

By the end of the year over 20 utilities and universities signed jointly funded contracts with the GHPC to develop pilot and major demonstration programs, provide A&E and HVAC contractor training, and improve ground heat exchanger design. Overall, the utilities have committed about \$20 million to match DOE's investment of \$10 million.

The Consortium, formed in late 1994, is an organization of electric utilities and their affiliates, equipment manufacturers, the Department of Energy, and the Environmental Protection Agency. The collective goal of the Consortium is to reduce greenhouse gas emissions and the cost of space conditioning and water heating. The Consortium aims to increase annual sales of GHP units from the current level of 55,000 to 400,000 by the year 2000. This will result in savings of over 300 trillion Btu's annually.

FENTON HILL HOT DRY ROCK FACILITY DECOMMISSIONED

Concurrent with its decision to redirect HDR work in the United States, the USDOE decided to decommission and close the HDR field test facility at Fenton Hill, New Mexico. Between March and December of 1996, 3 of the 4 deep geothermal wells at Fenton Hill and all but a few of the numerous shallow wells that had been used for heat flow measurements, seismic tool emplacement, and other supporting activities were plugged and abandoned. The surface plant was completely dismantled and other decommissioning

measures were implemented. Essentially all of the geothermal equipment and materials were placed in indefinite storage at Fenton Hill for possible application in future DOE projects.

Responsibility for the few remaining wellbores is being assumed by the Los Alamos National Laboratory. These will be used for a variety of petroleum and tool development projects currently underway and will be available for future projects that may be undertaken by the Laboratory. Many of the assets at the Fenton Hill site will be transferred to other Los Alamos projects. The ponds at the site, for example, will be transferred to an astrophysical project that is already underway. The United States Forest Service, the owner of the property on which the Fenton Hill HDR facility was developed, has also expressed an interest in using the site for training forest fire fighters. It thus appears that Fenton Hill will continue to be utilized for many years into the future, but its role in HDR development has come to an end.

Restructuring of HDR work was announced in late 1995. The US DOE stated that it intended to defer commercialization of HDR technology and instead would refocus the HDR program to "work with industry and other interested parties to resolve the key technical issues." The DOE developed plan is to issue a solicitation to obtain services to manage the national Hot Dry Rock (HDR) activities. The contractor will be required to interact with industry and government to integrate HDR activities with industry needs for a balanced and efficient research program that is responsive to both industry and DOE needs. Moreover, it is hoped this effort will bring the program more in line with the Industry Panel recommendations.

TRANSFER OF LONG VALLEY WELL ON SCHEDULE

Sandia National Laboratories entered into a formal agreement with the U.S. Geological Survey to transfer the Long Valley Exploration Well to that agency. The USGS plans to deepen the well from 7,500 to 10,000 feet if funds can be secured. Otherwise, the USGS will use the well to monitor earthquake activity.

The well was used by the DOE geothermal R&D program to investigate whether a magma chamber resides at relatively shallow depths and to explore its use for power generation purposes. However, after reaching depths in excess of 7,000 feet, DOE R&D policy shifted placing greater emphasis on projects of immediate interest to industry. As a result, magma research was suspended, and the well was subsequently used to conduct scientific investigations. Among other participants, DOE's Office of Basic Energy Sciences obtained critical information on the structure and evolution of the caldera. The California Energy Commission provided support to evaluate the long-term potential of magma as an energy source within the state, for the 21st century and beyond.

THE INDUSTRY SCENE

CALENERGY'S MASON SAYS GEOTHERMAL INDUSTRY IS HEALTHY; OUTLINES COST-CUTTING STRATEGIES

"I am here to tell you that the geothermal industry is alive and well in Omaha," Thomas R. Mason, President and CEO of CalEnergy, Inc., told the audience at Program Review XIV. "Even the company's plants at Desert Peak in Nevada and its Vulcan plant in the Imperial Valley remain profitable, even though they have gone off the SO-4 cliff," he said. Mr. Mason explained that a lot of joy has gone out of the process since plants have had to be run with fewer people and less availability. He pointed out that while it is much nicer to get 12 cents/kWh than it is to get 2.3 cents/kWh for energy, he emphasized that "the world is not coming to an end when rates fall off the cliff."

He noted that the low avoided cost rate is attributable to:

- Utilities who want to pay their IPP competitors less for their generation
- Utility commissions who want the benefits to flow to the rate payer
- Rate-payer advocates who want lower prices; and
- No consideration of the value of externalities or of the local economy.

In his address entitled, "Improving the Competitive Position of Geothermal

Energy," Mason detailed the steps taken by CalEnergy to reduce its costs. He indicated that one of the things that can be done by the geothermal industry to control costs during construction is "to joint venture with your ownership partner for construction to make sure you are doing what you can to control the profitability of the contractor by making a good portion of that profitability yours." He further emphasized that all available technology options that allow reduced installation and/or operating costs should be examined. "Sometimes it makes more sense to spend a little bit more money on the plant for the long-term benefits that result," he said.

He pointed out that manpower reductions can be achieved by combining wellfield and plant operations through cross training. In addition, he noted that in international projects, it is much less costly to hire and train a local work force.

Mason also noted other means through which CalEnergy has been able to cut its expenses, including:

- Acquisitions and an ability to have a smaller group run more operations
- Reducing management layers by consolidating and reducing duplication of efforts
- Completing construction projects ahead of schedule and under budget
- Reducing insurance costs through an outstanding safety record
- Assembling creative financing, and

- Consolidating and standardizing purchasing procedures.

CalEnergy has contracts for 500 MWe at three plants in the Philippines. The 125 MWe Upper Mahiao project (Figure 1) is in operation. A hybrid design, it includes four General Electric noncondensing steam turbines and 13 Ormat binary units. The plant design is notable in that air-cooled

condensers are used and all process fluids are maintained at above-atmospheric pressure.

The company's first plant in Indonesia is a 55 MWe unit at Dieng. The Dieng contract allows for up to 400 MWe. Along with similar contracts at Patuha and Bali, CalEnergy can potentially develop 1,200 MWe in Indonesia.

Figure 1. CalEnergy / Ormat Power Plant at Upper Mahiao, The Philippines

UNOCAL'S HULSE SEES COMPETITION AS KEY TO GEOTHERMAL SUCCESS IN NEXT FIVE YEARS

Darcel L. Hulse, Unocal's Group Vice President, Geothermal and Power Operations, spoke about the value of competition for the future of the geothermal industry at the Geothermal Program Review XIV. He focused on the

technological advances needed to increase the competitiveness of geothermal power in world energy markets -- technology to map the productive parts of hydrothermal systems and technology to increase the efficiency and reduce the cost of drilling in volcanic environments.

Using Unocal's oil and gas operations in Thailand as an example, Hulse illustrated how technological solutions can turn some failures into successes. He said that during the 1970s Unocal used marine seismic technology to map an area in Thailand.

The map suggested the presence of a very large gas field. However, after many manhours and a large investment, a completely different and unexpected type of structure was found, one so complex that the best geophysical technology of the time failed to resolve it. "The news was very discouraging and certainly destructive of project economics. However, improvements in technology have helped avoid such discouragements," Hulse noted. Elaborating on the results of improved technology, he said that new 3-D seismic technology accurately imaged faulting in the basin and identified some of the gas reservoir directly. Drillers learned to drill wells in Thailand for 75 percent less than the cost of wells in 1980; wells that once required 10 weeks to drill are now completed in 10 days. As a result estimates of the recoverable resource greatly increased. "These are the same kinds of advances needed to increase the competitiveness of geothermal power," he emphasized.

"There is no positive cash flow nor return on investment until a project is completed and the high costs of exploration and drilling have been incurred," Hulse noted. He used a simple model to demonstrate the effects of cost reductions achieved through use of better technology. In doing so, he noted that based on the time value of money, one dollar saved at the front end of a project is worth two dollars in the latter stages of the same project. He went on to explain that if the geothermal industry were able to increase well productivity by 20 percent and reduce plant and drilling costs by 20 percent, geothermal power would suddenly become competitive in the market place.

He pointed out that the geothermal industry has yet to understand permeability and the geological controls affecting its distribution in hydrothermal systems. He called for basic studies to allow advances in drilling and well targeting and noted that

some of the new geophysical methods, such as acoustic fracture mapping, may prove beneficial.

As to the needed breakthroughs in drilling, he emphasized technology for drilling in volcanic environments. He highlighted the importance of well size on project economics by explaining how wells with standard completions that produce less than 5 MWe could produce over 20 MWe as big holes. At Unocal's Salak project in Indonesia, the first four conventional production wells had an average output of about five megawatts each. The next well drilled, using large bore technology, had a hole diameter of 13 5/8 inches and a 9 5/8-inch liner. The big hole program focused on achieving economic benefits from increased productivity as well as reducing drilling costs.

By combining these two aspects of development, Unocal has been able to reduce overall costs. "The big hole made a large jump," but "we have taken that cash and cut another 25 percent through recent improvements in drilling." Mr. Hulse also pointed out these improvements cannot be made at one well at a time scattered all over the world. He indicated the need for large drilling programs where the industry can put together and see the benefits of marked improvements in technology over a period of time.

Mr. Hulse concluded his speech with the following advice. "We realize that there are now more worthwhile and valuable projects out there than there are people and resources to apply. The temptation to try to do all of the projects at a reduced level of effort should be avoided. This would delay progress in all areas, dilute the effectiveness of our people and capital, and cause the sponsors of research to lose interest in the technical program."

CALENERGY COMPLETES NEW PLANT AT SALTON SEA AND BUYS EDISON'S REMAINING INTERESTS THERE

In mid-1996, CalEnergy Company completed the construction of Salton Sea Unit IV, a 40 MW net geothermal flash plant in the Imperial Valley of California. The plant sells power to Southern California Edison under a modified Interim Standard Offer 4 (ISO4) agreement. The agreement combines two previous Edison power purchase agreements to which CalEnergy held the rights. One, with Unocal, was a negotiated contract for a 20 MW expansion at the Salton Sea facility, and the other, with Magma Power, was an ISO4 contract for a new 14 MW plant at Fish Lake, Nevada. CalEnergy acquired both agreements in its acquisition of Unocal and Magma assets. The contract provides for capacity payments on 34 MW at two different rates based on the original two contracts, and energy payments for deliveries up to 39.6 MW. The contract has a 30 year term. This is the first new geothermal electric capacity built in the U.S. since 1993.

Also, in March 1996, CalEnergy acquired the remaining half interest in four geothermal power plants at the Salton Sea field in the Imperial Valley, California, from its partner Edison Mission Company. The four plants with their nameplate ratings are the Vulcan with 34.5 MWe, and the Leathers, Elmore, and Hoch plants with 35.8 MWe each. CalEnergy purchased the equivalent of 70 MWe capacity for \$70 million or \$1,000 per kW. Magma Power Company was the original developer of these plants.

Sources: CalEnergy SEC filing; GRC Bulletin 5/96

CALENERGY REPORTS MAJOR INCREASES IN REVENUES AND EARNINGS

Reflecting the cost-cutting strategies described (see above) by Thomas R. Mason, President and CEO of CalEnergy, the company announced major increases in its revenues and earnings for the calendar year 1995 and, as of this writing, for the first three quarters of 1996 (Table 1). The company experienced a 115 percent increase in revenue from \$185.8 million in 1994 to \$398.7 in 1995 and a 96 percent increase in earnings from \$31.8 million to \$62.3 million over the same period. Such significant growth was attributed to improved operating performances coupled with the February 1995 acquisition of Magma Power Co. This acquisition enabled CalEnergy to strengthen its geothermal capabilities for both relatively benign and hostile type resources found at its Coso and Salton Sea plants, respectively.

Table 1.		
CALENERGY COMPANY, INC. PERFORMANCE IN 1996		
Period	Percent Increase	
	Revenues	Earnings
Q1	4	69
Q2	19	39
Q3	50	37

CALENERGY MOTHBALLS OPERATIONS AT NEWBERRY, OREGON

On July 17, the company informed the Bonneville Power Administration (BPA) that the geothermal resources on its leases at Newberry, Oregon, are insufficient to meet its obligation under the power purchase agreement on a cost-effective basis due to unexpected geological conditions and that it will relocate the project to an alternative location. A 30 MWe plant had been planned at Newberry.

The "alternative location," which a provision of the BPA agreement gives the company the right to propose, is Glass Mountain in northern California. A spokesman for BPA said that his agency could not immediately approve the move before making sure that the requirements of the National Environment Policy Act are fulfilled. In the meantime, CalEnergy has submitted a Plan of Operation for the Glass Mountain site to the Bureau of Land Management, a requirement of all lessees under the Geothermal Steam Act. This step indicates that the process for preparing an Environmental Impact Statement (EIS) has been set in motion. The EIS is expected to be completed sometime in 1997.

The BPA spokesman also reported that the Newberry site has been cleaned up and completely shut down. "Its mothballed state is such a shame because the project had been completely permitted," he said.

CALPINE AND TRANSPACIFIC PURSUE NEW DEVELOPMENTS

In April, Calpine Corporation in partnership with TransPacific Geothermal Corporation reached an agreement with the Bonneville Power Administration (BPA) to begin an environmental impact study (EIS) for the development of a 30-MWe (net) geothermal power generation facility at the Glass Mountain Known Geothermal Resources Area. Earlier Calpine signed an agreement with the Los Angeles Department of Water and Power (LADWP) to produce steam and electricity from the LADWP's Coso leaseholds in Inyo County, California.

Glass Mountain, located about 50 miles south of Klamath Falls, Oregon, in northern California, is one of the largest undeveloped geothermal fields in the U.S. The EIS will cover the power plant, a 24-mile transmission line, and related power purchase agreements. Calpine and Transpacific have a contract with BPA and the city of Springfield, Oregon, to develop a 30-MWe plant with options for an additional 100 MWe. Construction of the initial phase is to begin in 1997 with commercial operation scheduled for 1999.

The Calpine/LADWP agreement provides for power sales and subleasing under which Calpine would provide LADWP up to 150 MW of electric capacity. Amendments provide that the purchase and sale obligations do not come into effect until LADWP exercises its options to take the electricity. But Calpine has been granted the right to develop LADWP's leaseholds at Coso to produce steam or electricity for sale to third parties. LADWP acquired its Coso lease in the early days of the Federal geothermal leasing program, but its earlier announced plans to construct power plants were not realized.

CALENERGY WINS ITS BATTLE WITH H₂S AT COSO

CalEnergy's efforts to contain hydrogen sulfide emissions from its plants at the Coso Known Geothermal Resource Area have been increasingly effective. Since 1991, the company has spent \$30 million to improve the performance of abatement equipment and for annual operating and chemical expenses. Further, the company has taken aggressive efforts to meet or exceed the H₂S emission limits set by the California Ambient Air Quality Standard (CAAQS) and the more stringent emission requirements of the Great Basin Unified Air Pollution Control District (GBUAPCD).

Initially, CalEnergy installed high-pressure gas compressors to inject all the noncondensable gases back into the reservoir. However, this resulted in periodic gas breakthrough between production and injection wells, causing gas build-up in some production wells. Further, constant equipment breakdowns and high operating costs resulted in exceedances of GBUAPCD point source emission limits.

Next, the company installed the Hondo H₂S abatement system, a "batch" type process using gas compressors. The system proved effective in abating H₂S and solving the noncondensable gas recirculation problem. But, the same equipment breakdown problems did not permit reduce exceedance levels. The costs of abatement chemicals were also high.

The SulFerox system came next. Due to its continuous-duty feature and lower noncondensable gas pressure requirements, the system allowed shutdown of problematic compressors, resulting in reduced exceedance levels. However, chemical costs were still excessive.

In 1994, CalEnergy achieved improved results with the LO-CAT II system which measurably reduced exceedances and reduced chemical costs to less than 50 percent of those associated with SulFerox. The company now produces agricultural-grade sulfur for resale as a result of improved H₂S abatement systems.

AVAILABILITY 90 PERCENT AND ABOVE FOR FIRST TEN YEARS AT DESERT PEAK

The 10-MWe geothermal power plant at Desert Peak, Nevada, completed its 10-year contract period as a "qualifying unit" on January 1, 1996. During this period, the plant had an overall availability of 90 percent, which at times reached 99 percent.

In 1985, Sierra Pacific Power Co. was authorized by the Nevada Public Service Commission to sell electricity from the Desert Peak plant for 6.7 cents/kWh. Since completion of the 10-year contract, CalEnergy, the new owner, has been selling power to the utility for 2.56 cents/kWh on a Public-Service-Commission-approved, avoided-cost contract that is renewed every six months. CalEnergy has recovered its capital investment in the plant and has reduced its operating and maintenance costs below the current selling price.

GEOHERMAL ENERGY ASSOCIATION OPENS OFFICE IN WASHINGTON

The Geothermal Energy Association officially opened its Washington office with a reception in March which was well attended. The office's responsibilities and

activities are described in detail in Geothermal Progress Monitor No. 17, page 16. It does not engage in lobbying activities. Those are the exclusive domain of the Geothermal Resources Association, which has no formal connection with GEA.

Partial funding for the GEA office is provided by DOE, while other funding for specific projects comes from the U.S. Export Council for Renewable Energy. Membership dues and profits from the GEA-sponsored Trade Exposition at the GRC annual meeting also provide support.

During 1996 the office co-sponsored with GRC a conference in Mexico on financing geothermal projects, well attended by U.S. representatives and their Mexican counterparts. The office also sponsored a successful renewables workshop in Nicaragua and provided representation at a meeting in El Salvador convened to explore among other things, the possibility of a backbone transmission line in Central America. If this line is indeed constructed, the possibilities for geothermal development will be markedly enhanced in all Central American countries. GEA representatives also attended an energy meeting in Bolivia.

An outreach working group composed of GEA staff and others help in development of outreach materials. Two new pamphlets, one on geothermal facts and one on member companies and services they offer, have been printed. Participation in the Sustainable Energy Working Group, a Washington based coalition of environmental and energy advocacy groups, has continued.

A reception was sponsored in March to honor Senator Mark Hatfield of Oregon who retired at the end of the year. A GEA Lifetime Achievement Award was presented along with a core sample from the Newberry, Oregon, geothermal prospect. A luncheon was also sponsored

for Rep. Dan Schaeffer of Colorado who submitted a bill on the restructuring of the U.S. power industry that is quite favorable to the geothermal industry, and who formed the House Renewable Energy Caucus, a bipartisan group consisting of about 100 House members.

GAS STATION'S GHP SYSTEM FINDS EFFICIENCY IN MANY PLACES

A geothermal heat pump (GHP) system is the heating and cooling centerpiece of a new Phillips 66 gas station and convenience store in Prairie Village, Kansas. What has made this the company standard for new station construction particularly attractive is its novel and highly efficient integration of convenience store coolers and freezers into one system.

The system uses a closed loop heat exchanger of Phillips Driscopipe, installed in ten 325-foot (110 meters) wells, located around the perimeter of the station. A 5-ton heat pump connected to this loop takes advantage of the earth's relatively constant temperature to provide cooling in the summer and heating in the winter.

The station's 4-ton walk-in cooler, freezer, and ice maker -- all of which reject a substantial amount of heat that would ordinarily be wasted -- have been tied into the system and contribute to a very high overall efficiency. Future stations will also incorporate water heating options for car washing and ice melting purposes.

According to J.J. (Joe) Brown, Senior Supervisor of retail projects for Phillips Petroleum, the system design contributes to improved equipment performance in addition to energy savings.

At a conventional station, there are several pieces of heating, cooling, and refrigeration equipment installed on the roof. Quite often, the hot air exhaust from one unit is pulled into the cold air intake of another, greatly reducing equipment efficiency. "Our design puts all the equipment inside the store, eliminating any 'short-circuiting' and allowing us to reduce cooler and freezer compressor sizes," said Brown. Instead of air-cooled, reach-in coolers and freezers, the company chose water-cooled equipment connected to the GHP system which results in a 40-percent drop in electrical consumption. This is in addition to the savings from using smaller compressors. By coupling the water-cooled icemakers to the GHP system, the station saves approximately 1,500 gallons of condenser water per day at an average cost of more than \$4.00 per 1,000 gallons of city water. The GHP system also has fewer dirt-, debris-, and weather-related maintenance problems, and "it is easier to

get to the equipment for regular maintenance, plus the store has a cleaner, more appealing look, with less potential for vandalism," concluded Brown.

With its carefully planned energy efficient systems, an underground pipe warranty for 60 years, equipment life in excess of 20 years, and EPA endorsement, this system will save energy and money throughout the life of the station. DOE's Office of Geothermal Technologies reports that Phillips 66 has now installed GHPs in dozens of new stations and that Texaco, Conoco, Shell, and a few independents are following its lead. The Electric Power Research Institute and Oklahoma Gas and

Electric are monitoring two new Texaco stations using GHP systems in Oklahoma and report energy savings of around 40 percent.

Source: Kansas City Power and Light²

Figure 2. Phillips 66 Station at 9440 Mission Road In Prairie Village, Kansas, is the Company's Energy Efficient Model for all new construction

HOMES WITH GHPs WIN NAHB HOUSING AWARDS

Six of the twenty-one awards from the National Association of Home Builder's "Value in Housing Awards" were given to homes with a geothermal heat pump system for heating and cooling purposes. The awards were presented at the National Home Builders Show in Houston, Texas, in January of 1996. One builder, Russel Home Builders of Pensacola, Florida, has incorporated geothermal heat pumps in 90 percent of their new homes for the past eight years. The company, which builds about 20 homes per year, has found unmatched advantages from homes with geothermal heat pumps and tight thermal envelopes. Another recipient, Barbara Harwood of BBH Enterprises in Dallas, Texas, built a community of affordable housing where utility bills are well under \$1 per day for heating and cooling. The other winners were from Pennsylvania, Massachusetts, and Florida.

TECHNOLOGY DEVELOPMENT

THE GEYSERS: TECHNICAL ISSUES IN 1996

Current research efforts at The Geysers geothermal field were reported and discussed in a technical session at DOE's Geothermal Program Review XIV, April 8-10, 1996, in Berkeley, California. The session included the presentation of various papers and a panel discussion. Although injection was the predominant topic, papers were also presented covering geologic research, microearthquake source mechanisms, and Geysers power plant improvements.

The panel discussion, moderated by Marcello Lippmann of Lawrence Berkeley Laboratory, included the following participants:

- Ben Barker, Unocal Geothermal
- Keshav Goyal, Calpine Corporation
- Paul Hirtz, ThermoChem, Inc.
- Jeff Hulen, Energy and Geoscience Institute
- Collin Williams, U.S. Geological Survey

The panelists discussed what is known about The Geysers field and what critical things remain to be learned. They agreed that injection has been proven a viable method for increasing production and extending the life of the field and is, therefore, the single most important issue.

The panel concluded that research on the Geysers should be continued in the following areas:

- Injection
- Tracers
- Downhole fluid samplers
- Methods to determine the 3-D distribution of porosity, permeability, and fractures
- Origins and mitigation methods for HCl
- Deep coring
- Imaging logs.

Closer communication between the researchers and industry end users was also recommended. One panelist observed that the Geothermal Technology Organization (GTO) funded projects do not seem to suffer from communication problems and work fairly well because they are jointly funded by industry and DOE. These projects usually have very specific goals, clear time tables, and there is often good communication between all the participants.

Papers presented prior to the panel discussion included:

Geologic Research at The Geysers, Energy and Geoscience Institute, University of Utah. Geologic research at The Geysers during the past year yielded new information on the nature of steam-reservoir porosity and permeability; the origin of the caprock; mechanisms of lateral sealing; the evolution of the hydrothermal system; and specific reservoir controls in and immediately above "the felsite," an hypabyssal, batholith-sized pluton largely responsible for The Geysers' existence. Research has also shown that (1) fluid conduits above the felsite may be dominantly vuggy, high-angle hydrothermal veins; (2) latest-stage hydrothermal calcite

in such veins may seal them at the margins of the steam reservoir; mixed-layer clays are probably the corresponding seals in the caprock; (3) steam entries in the felsite are concentrated along the top of the youngest intrusive phase in the pluton — a one million year-old granodiorite; (4) steam entries in the felsite show a negative correlation with massive borosilicate enrichments.

Microearthquake (MEQ) Source Mechanism Studies at The Geysers Geothermal Field, Earth Sciences Division, Lawrence Berkeley National Laboratory. One of the main objectives of the LBNL program at The Geysers is to assess the utility of MEQ monitoring as a reservoir management tool. Better understanding of the mechanisms by which microseismic events occur may aid in the interpretation of occurrence patterns and their significance to reservoir processes and conditions. The types of failure deduced from source mechanism studies and their relation to production parameters should also lead to an improved understanding of the effects of injection and withdrawal.

After investigating the source mechanisms of 1,697 microearthquakes in the northwest portion of the field and 985 in the southeast sections, it is believed that the flashing of superheated water to steam is the most feasible mechanism to explain the occurrence of the events with positive volumetric components. Water is present in the reservoir as both an injectate and a naturally-occurring component of the mixed vapor/fluid reservoir. Thus, as observed, positive-type events would not be restricted to injection areas, although they could be expected to occur there with greater number. It also could account for the absence of MEQs from some areas of injection and extraction: if the reservoir pressure is high enough, water present in the systems will not flash to steam. Only after the pressure drops to some threshold value will conditions allow flashing and

consequent seismic activity.

Effects of Adsorption and Capillarity on Injection in Vapor-Dominated Geothermal Reservoirs, Stanford University Geothermal Program. Adsorption and capillary forces are major factors governing the behavior of a vapor-dominated geothermal reservoir. These mechanisms affect the resource size, production performance, and effectiveness of water injection programs. While water injection into vapor-dominated reservoirs causes reservoir pressure to increase, improving well productivity, it also increases water retention in the reservoir.

Geothermal reservoir simulators that use curved interface thermodynamics are now available. The hysteresis and temperature dependence of sorption and capillary properties are issues that still need to be addressed. These processes should be incorporated in future codes of geothermal reservoir simulators.

Turning Community Wastes into Sustainable Energy, Energy and Resources Manager, Lake County, California. On October 6, 1995, ground was broken for the Southeast Geysers Effluent Pipeline Project, the world's first wastewater-to-electricity system. A 29-mile, 20-inch diameter pipeline will carry up to 7.8 million gallons of wastewater a day for injection to depths of approximately 8,000 feet (2,432 meters). This will provide an environmentally acceptable means of waste disposal and increase resource sustainability. When construction is completed in 1997, the project will begin a 25-year operating life providing the Lake County communities with not only all their electrical needs, but also sufficient wastewater disposal capacity to accommodate regional growth to 2022.

The \$45 million cost of the project was shared by local, state, federal, and corporate stakeholders. Depending on

Figure 3. Layout of Wastewater Pipeline To The Geysers Geothermal Field

steam recovery rates, the project is expected to produce up to 70 MWe of generating capacity at six existing plants, or as much as 520,000 MWh annually.

PG&E's Geysers Power Plant Improvements -- Past, Present, and Future. PG&E Research and Development Department. Past power plant retrofits at Pacific Gas and Electric's Geysers power plants include innovative H_2S burners that reduced chemical costs and a turbine jack-shaft that improved unit efficiency. Other important retrofits that dramatically reduced turbine forced outage and repair costs include turbine blade and nozzle changes, turbine weld repairs, and steam desuperheating.

Retrofits in progress include turbine steam path modifications and a high-speed turbo-compressor to improve plant efficiency. Installation of an advanced direct contact condenser will improve the

steam rate by as much as 5 percent and dramatically reduce H_2S abatement costs. New turbine rotors with titanium blades will also eliminate stress corrosion cracking, without the need for steam desuperheating.

Current steam desuperheating effectively controls stress corrosion cracking of turbine blades, but at a cost of about 20 MWe of energy otherwise available for power production. Further, several more megawatts of heat energy are available at the H_2S burners, but economical heat recovery will be difficult because the exhaust gas is quite corrosive. Additional research is needed to improve H_2S emission monitoring and develop technologies to reduce hazardous waste disposal costs. And finally, finding additional innovative and economical methods of bringing water for injection into The Geysers could sustain and renew this valuable energy resource.

COOPERATIVE R&D Will INCREASE OUTPUT AT PG&E UNIT 11

The application of two new technologies at The Geysers is expected to improve the performance of Pacific Gas & Electric's (PG&E) Unit 11 power plant and extend the life of the steam field. These improvements are an Advanced Direct Contact Condenser (ADCC), developed by the National Renewable Energy Laboratory, and a Turbine Compressor, designed and built by Barber Nichols, Inc. for enhanced noncondensable gas removal under an agreement reached by the Geothermal Technology Organization and DOE.

The demonstration of NREL's ADCC technology is being conducted under a cooperative Research and Development Agreement (CRADA) between DOE and PG&E. Participants in the installation of the turbine compressor include DOE, PG&E, Barber Nichols, and Unocal Geothermal.

PG&E's estimates for its Unit 11, selected as the best case because of its high noncondensable gas load and considerable steam carryover in the gas removal system, are an overall 4.5 MWe improvement in power production. Of this, 4.5 MWe are expected to accrue from lowered back pressure and 2.5 MWe from improvements in the gas removal system. In addition, substantial reductions in abatement chemical usage are expected.

Figure 4. Schematic of The Geysers PG&E Unit 11 Power Plant Including Process Modifications

ADVANCES IN TOUGH2 RESERVOIR SIMULATORS ENHANCE USEABILITY

TOUGH2 is a general-purpose fluid and heat flow simulator with applications in geothermal reservoir engineering, nuclear waste disposal, and environmental contamination problems. It is the latest in the family of simulation codes developed by the Lawrence Berkeley National Laboratory. Researchers at the laboratory's Earth Sciences Division announced a number of recent developments that enhance the useability of the code at Geothermal Program Review

XIV. These improvements are expected to provide a more accurate and comprehensive description of reservoir processes.

The recent developments of interest to the geothermal community include those shown in Tables 2 and 3. The status codes are (PR) public release, (β) Beta-testing underway, and (I) in-house use only.

The TOUGH2 code and the upgrades released are available from Energy Science and Technology Software Center, P. O. Box 62, Oak Ridge, TN 37831. Phone: (423) 576-2606; Fax: (423) 576-2865; e-mail: estsc@admis.osti.gov.

Table 2. NEW MODULES IN TOUGH2 FAMILY OF RESERVOIR SIMULATORS

Module ^(status)	Purpose of Module
T2CG1 ^(PR)	Preconditioned conjugate gradient solvers for simulation of large 2-D and 3-D problems with 10,000 grid blocks or more
TOUGH2 for PC ^(PR)	Adaptation of TOUGH2 for Personal Computers (PC)
T2VOC ^(PR)	A module for 3-phase, 3-component flow of water, air, and a volatile organic compound (VOC)
ITOUGH2 ^(β)	Inverse modeling, allowing automatic model calibration (history matching), and process optimization, with applications to test design, reservoir management, and environmental remediation
T2DM ^(β)	Strongly coupled flow and transport with full hydrodynamic dispersion
MULH ^(β)	Flow in strongly heterogeneous media (spatially correlated random permeability fields)
T2HYST ^(β)	Hysteretic capillary pressure relationships

Table 3. NEW FLUID PROPERTY MODULES FOR TOUGH2	
Module^(a)	Properties of Module
EOS6^(b)	Water with silica dissolution and precipitation
EOS7^(b)	Mixtures of water, brine, and air
EOS7R^(b)	Mixtures of water, brine, and air, plus volatile tracers with optional parent - daughter chain decay
EOS8^(b)	Three-phase flow of water, non-condensable gas, and black oil
EOS9^(b)	Saturated/unsaturated flow according to Richards' equation (gas phase a passive bystander)
EWASG⁽ⁱ⁾	Three-component two-phase mixtures of water, water-soluble salt, and non-condensable gas. Includes salt dissolution and precipitation, and associated porosity and permeability change.
ECH4⁽ⁱ⁾	Water and methane
EGEL^(b)	Two-phase flow of an aqueous and a gas phase, where the aqueous phase may consist of a mixture of water and a gelling fluid
E0SNN^(b)	Three-phase flow of water, non-condensable gas, and a non-Newtonian fluid
EOSIG^(b)	Fluid property module for single-phase gas flow

RESERVOIR STUDIES CHANGE SOME CONCEPTS AND REDUCE TRACER COSTS

Researchers at the Energy and Geoscience Institute (EGI, formerly ESRI), University of Utah, are conducting ongoing studies of fractures in high temperature geothermal systems at the microscopic and regional levels. These studies will yield a better understanding of fractures that will pay off in exploration success, fewer dry holes, and more efficient resource utilization. Since faults are heterogeneous fractures, selected examples are being studied to

better understand their geometry and permeability distributions.

A conceptual model based on detailed outcrop mapping has been developed to aid in evaluating the physical properties of fault zones. The model provides a framework for determining spatial variations in fault zone architecture from field data and for incorporating physically-based geologic information into mathematical models of fluid flow in faulted rocks. Since the fluid flow properties of a fault zone may change, a conceptual model usually represents only a single point in time. For example, a fault's core may act as a conduit during deformation, but as a barrier to flow when open pore space is filled by mineral

precipitation following deformation. Therefore, it is important to specify the stage of fault evolution when forming a conceptual model for a particular fault zone.

Field work on faults has focused on detailed mapping of fracture networks at the footwall of the Dixie Valley and Stillwater fault zones in Nevada. The collected data were used to upgrade the conceptual model and to overcome the constraints of simulating fluid flow within and/or near the fault zone.

Continuous core recovery from the upper part of The Geysers steam field provided a wealth of new information. Core analysis revealed information about the geometry of permeability control in the field and demonstrated that the fractures are of predominantly high-angle orientation. This is contrary to earlier conclusions that the controlling fractures are of low-angle orientation based on the geometry of production from adjacent wells.

Core samples recovered from the Tiwi geothermal field in the Philippines, taken at approximately 2,500 and 8,000 feet (960 and 2,432 meters), also demonstrated that permeability was totally controlled by high-angle fractures. Earlier production data had suggested a relatively flat permeability, thought to have resulted from fluid flow along stratigraphic horizons. Often times, fractures contain abundant hydrothermal minerals and determining their origin becomes very difficult.

EGI's fracture permeability study has concentrated on the behavior of rock in the brittle zone. Much of a geothermal system's heat content and development potential lies stratigraphically below and at temperatures greater than about 400°C (752°F), where rocks behave in a ductile fashion. The deep wells at Larderello, Italy, and at Hakkonda, Japan, provide evidence of such behavior.

This indicates the significance of heat recovery from deeper parts of geothermal systems, an important consideration for the future of the industry. EGI has developed a model (see Figure 5) that depicts the transition of rocks from the brittle to the ductile state, which probably defines the limits of fluid circulation in most high-temperature systems. Therefore, EGI concludes that Enhanced Heat Recovery can be realized with deep injection, which accelerates the natural heat transfer process and allows economic heat recovery.

The EGI tracer program includes development of liquid- and vapor-phase tracers, and pre-test modeling of both. Numerous aromatic acids and fluorescent dyes have been tested as liquid-phase tracers. For the vapor phase, current focus is on testing SF₆ at high temperatures and examining HPLC methods for sensitivity analysis of alcohol tracers. The pre-test modeling activity is exploring the feasibility of using simple numerical models to lower the cost of tracer tests by providing estimates of tracer quantities, flowpaths, and arrival times.

The results of earlier EGI tracer research reported to Program Review XIV have impacted geothermal operating costs in several ways. First, the data derived from laboratory and field studies have reduced the number of false negatives -- i.e., lack of tracer detection in production wells during tests due to 1) insufficient amounts of tracer used, 2) tracer decay, and 3) inadequate test design. False negatives represent the largest costs of running tracer tests.

Recently, natural organic tracers have been developed for use in place of halides. This reduces the quantity of tracer needed, lowers material costs, and avoids the effects of high-density slugs, which sink to the bottom of the reservoir instead of flowing to the production wells.

Work on detection limits has also reduced the amount of material required for a tracer test. A drop in detection limits of a thousand-fold, which has been accomplished with fluorescent dyes, theoretically lowers the amount of tracer from 100 kilograms to a tenth of a kilogram, or, alternatively 100 kilograms can be used with a large margin of error.

Stability tests have determined the maximum temperatures sustained by each tracer, which permits avoiding negative tests where the tracer decays before

reaching production wells. Further, work on fluorescent tracers has enabled operators to use several tracers simultaneously and still analyze the tracers on site.

Pre-test modeling of tracers in reservoirs affects the size and costs of sampling in the same way that detection limits affect tracer material costs. Targeting the probable wells and the injection velocities lowers the frequency of sampling, cutting manpower and analysis costs.

EGI feels that use of a known tracer in conjunction with those being tested has led to low-cost, high-quality tracer tests, good reservoir information, and published experiences in tracer usage.

Figure 5. Schematic Model for Zonation Within Active Hydrothermal System

IMPROVEMENTS CONTINUE IN CHEMICAL MODELS FOR GEOTHERMAL APPLICATIONS

The Geothermal Brine Chemistry Model, developed at the University of California at San Diego, is a user-friendly package that simulates changes in chemical and physical properties of geothermal brines. The model is designed to improve the productivity and efficiency of geothermal operations by enabling operators to adjust key process variables and rapidly analyze potential brine chemistry-related problems. It also permits development of viable abatement strategies.

The model has been upgraded with a capability to calculate the enthalpy of geothermal fluids for a large range of temperatures, pressures, and steam fraction. An improved graphical interface for Macintosh and PC machines was also announced at DOE Geothermal Program Review XIV. In response to user requests,

the following new features have also been incorporated:

- Options for scaling brine mixtures. A user may now select scaling parameters by changing values listed in a user interface window. For example, the proportion with which to mix two brines or an evaporation rate may be selected.
- Temperature units may be selected in either degrees Celsius or degrees Fahrenheit from a pull-down menu.
- Concentration units may be chosen from a pull-down menu. Currently, molality and parts per million are suggested.
- Input data file storage and retrieval options.
- New options giving model flexibility. The TEQUIL user interface program reads a file that contains a list of files that define the model: the name of the Fortran executable, the names of the parameter files, and the name of a description file that tells the user what components make up the model and what temperature range it covers.

SANDIA'S ADVANCED DRILLING SYSTEMS STUDY HIGHLIGHTS PENETRATION RATE

Sandia National Laboratory researchers developed a system performance and economics methodology to evaluate advanced drilling systems as potential candidates for research and development. This required identifying the system components, including: the basic drilling functions, systems constraints, system concepts, operating costs, performance requirements, common problems, and the size of the surface system.

The six basic drilling functions identified are: 1) energy transmission to the system-rock interface, 2) rock reduction, 3) debris removal, 4) borehole maintenance while drilling, 5) well control, and 6) preservation of the borehole. Technical constraints on the performance of these functions include directional drilling and control as well as sensing and communication constraints. Institutional constraints include environmental impact, operational safety, and government regulations.

The concepts and systems studied are listed in Table 4. Most of the concepts are familiar to anyone who has followed the efforts to develop novel drilling systems. The only concept that is less than twenty years old is the Pulsed-laser water-jet, proposed and investigated by PowerPulse Systems of Lakewood, Colorado.

Table 4.

SYSTEMS AND CONCEPTS

- Conventional rotary technology
- Coiled tubing drill rig
- Rotary-assist:
 - Jet-assist
 - Projectile-assist
 - Thermal-assist (microwave)
- Mud hammer
- Thermal spallation
- Jet drilling
- Spark drill
- Explosive drill
- Rock melters:
 - Electric heater
 - Laser thermal
 - E-beam
 - Plasma arc
- Pulsed-laser water-jet

Performance assessment for most advanced concepts is difficult. The

technical maturity varies dramatically from concept to concept. Data for some systems were obtained from field tests, while other systems have not progressed beyond bench tests, and still others have yet to be tested as a system in any format. It is neither easy nor accurate to extrapolate expected performance characteristics from such data.

Instead of estimating performance capabilities, performance requirements were estimated. These requirements are based on the necessary penetration rate and bit life such that making hole and completing it with the advanced technology will cost no more than would use of conventional rotary technology over a specific drilling interval.

Using the systems approach, some facets of a problem that would prevent successful deployment of the entire drilling system were found and a number of common problems that run across multiple systems were identified as listed in Table 5. The solution to one of these problems could advance the viability of all the systems cross-cut by that problem.

<p style="text-align: center;">Table 5.</p> <p style="text-align: center;">COMMON PROBLEMS</p>
<ul style="list-style-type: none"> - Multi-channel conduit - Electric conductor downhole - Maintenance of borehole gage - Control of stand-off distance - Trajectory control - Well control and wellbore stability in the absence of liquids - Reduced effectiveness with depth - The size of the surface system

Results show that the size, cost, and complexity of a drill rig's surface system, which accounts for the vast majority of total expenditure, are little affected by the way rock is cut. The sizes and specifications for the mast, substructure, and drawworks are determined by the need to handle casing. The requirements of the mud pumps, pits, and mud-cleaning equipment are determined by the size of the cuttings and the rate at which they are produced. About the only equipment that depends on how rock is cut is the bottom hole assembly. Further, it is doubtful that any novel rock cutting mechanism will cost less than drill collars, stabilizers, and bits. Overall, it is unlikely that significant savings in materials and equipment can be achieved by simply changing the way rock is cut.

Similar conclusions are reached when daily operational costs are considered. The number and skills of the crew are determined by the surface equipment. Rig insurance is determined by capital investment; liability insurance and workman's compensation costs are proportional to payroll. While the rig is turning, the power delivered to the rotary table or top drive is generally less than 30 percent of the total power usage on the rig. And in any event, all rock-cutting mechanisms require energy delivery in some form.

Thus, since neither capital investment nor daily operational costs are significantly affected by the way rock is cut, it is concluded that reduction of drilling costs can occur only by changing the nature of the drilling system or by increasing the rate of penetration.

NADET FUNDS SEVEN ADVANCED DRILLING RESEARCH PROJECTS

The National Advanced Drilling and Excavation Technologies (NADET) program announced the award of funding for seven advanced drilling research projects. While the seed money for the NADET program was provided by the DOE Office of Geothermal Technologies in recognition of the importance of advanced drilling systems for geothermal development, NADET also funds projects that are relevant to a much wider range of advanced drilling and excavation systems.

The NADET Institute at the Massachusetts Institute of Technology was established to administer solicitations and project selections leading to the funding awards. Currently, efforts are underway to secure broad support for a multi-industry program.

The seven research projects selected for funding include:

Mud Jet-Augmented PDC Bit for Use with Conventional Rig Pressures. Sandia National Laboratories, Security DBS, Dynaflo, and Terra Tek. The project will develop and demonstrate the effectiveness of a mud jet-augmented PDC bit that drills with improved penetration rates and bit life in hard rock (>20,000 psi compressive strength) using mud pump pressures (<6,000 psi) that are currently available or can be economically installed on a drill rig.

Systems Analysis of Alternative Wellbore Lining Methods. Sandia National Laboratories and Livesay Consultants, Inc. The project will examine alternatives to the conventional practice of lining a wellbore with steel pipe, or casing, sealed in place by pumped cement after a relatively long interval of drilling a constant-diameter hole. A system which could line the hole as it is

drilled would be very cost-effective, for it would solve or mitigate problems caused by lost circulation, stuck pipe, wellbore instability, and faulty cement jobs. Many wells would also require fewer casing strings, and the casing would be of smaller diameter, accruing additional cost savings.

New Brazing Process for Attaching TSP Diamonds to Drag Bits. Technology International Inc., the Jet Propulsion Laboratory, the Colorado School of Mines, and Sandia National Laboratories. The project will: 1) Develop unique, high attachment shear and impact strength TSP diamond cutters with greater cutter exposure as lower temperature PDC cutters. 2) Design new TSP drag bits. 3) Demonstrate the capability to drill hard rock economically in laboratory and field tests. Two new brazing processes for attaching TSP diamond cutters to a drag bit body will be investigated, each with the potential to exceed current state-of-the-art attachment impact and shear strengths.

Improved PDC Drill Bits Incorporating Novel Processing of Cemented WC and Diamond Composites. Pennsylvania State University and Dennis Tool Company. The project will design an improved PDC drill bit using newly developed microwave sintering techniques. This technique offers reduced manufacturing costs and improved mechanical properties.

Advanced Geothermal Turbodrill. Maurer Engineering, Inc. The project will develop an advanced high-temperature turbodrill for drilling hard rock at high penetration rates. The turbodrill will use 50 sets of turbine blades to convert hydraulic power from the drilling mud to rotary mechanical power that drives the bit. A gear box will be added to reduce the speeds of earlier technology from 1,000 to 100 rpm for use with hard rock bits. Improved thrust bearings will be used to allow higher bit weights and increase the reliability of the turbodrill.

Binderless Nanophase Cutter Materials for High Rate Hard Rock Drilling, Diamond Materials, Inc. The recently developed a Binderless Polycrystalline Diamond (BPCD) exhibits superior thermal and corrosion stability over conventional PDC materials. The company will continue its research on BPCD materials with a focus on: 1) Performance under conditions encountered during geothermal drilling including bottomhole high-temperature corrosive environment. 2) Feasibility of integration of the cutters into corrosion and erosion resistant drill bits to be produced by high-temperature sintering methods.

High Performance Mini-disc Bit with Water Jet Flushing, Excavation Engineering Associates, Inc. The project will develop a high-performance bit. The basic science behind the use of very small, disc-type cutters called mini-discs, is that they slice the rock, creating tension failures and causing chips to pop off the rock face between the cutter tracks. Average size of the cuttings is larger than with conventional hard rock roller cone bits. Specific energy of excavation, energy consumed per unit mass of rock excavated, is reduced. For a given amount of power applied, a mini-disc goes faster. This research will focus on drill fluid circulation: pressure, injection points, and a controlled flow path within the bit.

FOUR DRILLING TECHNOLOGIES NEAR COMMERCIALIZATION

Four innovative drilling technologies developed at Sandia and which are nearing commercialization include: the rolling float meter, the pressure/temperature memory logging tool, the drillable straddle packer, and the core-tube latch detector.

KTECH Corp. of Albuquerque, New Mexico, is currently fabricating the first model of the second-generation rolling float meter based on Sandia drawings. The meter was developed for measuring the outflow rate of drilling fluids from a well, a function that helps detect lost circulation, steam kicks in geothermal wells, and gas kicks in petroleum wells. This second-generation design is based on changes identified as a result of five years of laboratory and field testing by Sandia and industry participants. The changes will improve the meter's sensitivity, accuracy, ease of use, and ruggedness as well as permitting compatibility with mass fabrication techniques. Epoch Well Logging, which was previously involved with the meter's use on a geothermal rig, is interested in evaluating the meter on an oil and gas rig. This is a potential lead to widespread use of the meter in geothermal as well as the oil and gas drilling industry.

An agreement has been reached between Sandia and Pruett Industries to commercialize the Sandia pressure/temperature memory logging technology. The tool, two inches in diameter and six feet long, can survive downhole while taking and storing data for eight hours at 400°F (204°C). It is relatively inexpensive to build and simple to transport and operate. It can be run inside the hole on a slickline cable that is already available on geothermal drill rigs. The tool downloads its memory to a notebook computer when retrieved back to the surface. DOE-developed software merges the downhole data with a surface data file and plots the pressure and temperature data as a function of borehole depth. The next enhancement steps will likely include adding an interface connecting the Sandia tool to both a Pruett spinner and a fiber-optic tubing, field testing the new system in cooperation with a geothermal operator, and then repeating the process with fiber-optic communication.

The drillable straddle packer, a downhole tool for use in improving the efficiency and success of cementing lost circulation zones encountered in geothermal drilling, underwent its final testing in June at Sandia's Engineered Lithology Test Facility (ELTF). The device allows cement to be pumped directly into the loss zone and seals it, averting loss of drilling fluids into the rock formation. The ELTF is a large outdoor facility where alternating layers of gravel and clay are placed to simulate downhole permeable and impermeable zones. A vertical concrete tube running through these layers simulates the wellbore. The facility has been used to study cementing techniques during lost circulation episodes. The successful application of the packer and the facility were demonstrated in the June test. Because of similar lost circulation problems, the packer has potential cross applications in oil and gas drilling.

In August, Sandia successfully tested two drilling accessories on a Tonto Drilling Company wireline core rig near Elko, Nevada. A core-tube latch detector and two core-tube memory tools were tested repeatedly and demonstrated to work as designed.

The core-tube latch detector is a hardware system that allows a driller to easily detect when the core-tube lands and latches in place inside the bottomhole assembly, indicating that drilling can proceed. Obtaining a positive, reliable indication of successful latching is a problem that currently costs the driller valuable time, sometimes adding about five percent to the cost of a well. The new system, designed and built at Sandia, detects the landing and latching sound that travels up the drill rod. It filters and amplifies the signal and plays it through a pair of noise-canceling headphones worn by the driller. The core-tube memory tools measure temperature and hole inclination.

Both were designed to attach to the top of the core-tube and travel with the tube as it drops down the drill string, latches in place downhole, and receives rock core during drilling. The tools store data during the entire process. When the core tube is retrieved, the memory tools are attached to a surface computer and the information downloaded. A total of 11 runs were made during the August test. Data from each run contain the entire history of a core tube cycle. The next step is to add heat shielding features to both tools for high-temperature applications.

SANDIA'S GHP RESEARCH FOCUSES ON REDUCING COSTS OF DRILLING AND INSTALLATION

Sandia's geothermal heat pump (GHP) program began in the early 1990s as a very broad-based activity that included demonstrating new installation methods, conducting performance measurements, undertaking limited technology transfer efforts, and performing R&D on GHP systems. The program was funded by both the DOE Office of Geothermal Technologies and the DOD Strategic Environmental Research and Development Program (SERDP).

However, two important changes occurred in FY 95-96 that affected Sandia's GHP efforts. The Geothermal Heat Pump Consortium was formed to develop and oversee joint projects with industry, demonstration and data acquisition type projects. In addition, the SERDP program was realigned toward technologies other than GHPs. As a result of these changes, since FY96 the Sandia program sharpened its focus toward R&D aimed at reducing the drilling cost of ground loop installations, particularly the vertical type, and understanding the performance of

ground heat exchangers in dry soils typical of the southwest. This change was done to conserve the reduced funding available and to focus on R&D connected to Sandia's established expertise in drilling technology.

Ongoing GHP projects at Sandia include:

- GHP loop installation systems study
- Low-cost, replaceable-cutter PDC bit for GHP drilling
- Planning and convening an annual vertical loop installation workshop
- Acquisition and analysis of vertical loop performance data at Sandia buildings with 18 GHPs.

ADVANCED GEOTHERMAL DRILLING SYSTEMS ARE A FOCUS AREA FOR 1996 DOE SBIR AWARDS

The Small Business Innovation Research Program (SBIR), managed by DOE's Energy Research Office, selected advanced geothermal drilling systems as one of the focus areas for its 1996 funding awards. The nine projects that received awards and firms undertaking the research and development are:

- Thermally Stable Polycrystalline Diamond Cutters for Hard Rock Drilling, Novatek.
- Nanocrystalline Superhard, Ductile Ceramic Coatings for Roller Cone Bit Bearings, Spire Corporation.
- Fatigue Weakening of Hard Rock with Cyclic Underbalanced Pressures, QUEST Integrated, Inc.
- Superhard Nanophase Cutter Materials for Rock Drilling Applications, Diamond Materials, Inc.
- High-Speed Bearing for Roller Cone Drill Bits Used in Hard Rock Drilling, Kalsi Engineering, Inc.
- An Autonomous Self-Propelled System

- for Hard Rock Drilling, APS Technology
- Very Low Friction Small Radius Domed Cutters for Percussion Drill Bits, Novatek
- Development and Testing of a Jet-Assisted Polycrystalline Diamond Drilling Bit, Novatek
- Advanced Low-Stress Bonding of Thermally Stable Polycrystalline Diamond Cutters to Tungsten Carbide Substrates, Science Research Laboratory, Inc.

Project summaries (Topic No. 27, Subtopic B) are available from: Energy Research Office, Department of Energy, Washington, D.C. 20585

GDO COMPLETES ROTATING-HEAD STRIPPER RUBBERS, CONTINUES OTHER PROJECTS

As part of a Geothermal Drilling Organization (GDO) project, Smith International has optimized rubber compounds for use in high-temperature, rotating-head strippers that seal against the drill pipe and force the drilling mud into the return line. The high temperatures inside geothermal wells cause conventional stripper rubbers to wear rapidly, requiring frequent replacements during drilling operations.

Laboratory tests at the company's facilities in Houston and later field tests found a butyl elastomer that proved satisfactory in both environments. Final testing for high-temperature applications of the butyl elastomer is virtually complete with very satisfactory results obtained from four samples that underwent testing in a California geothermal field. The GDO provided partial funding for the early and intermediate phases of this project.

The GDO is an organization of 17 member companies and national laboratories that

collaborate and cost-share short-term, industry-driven projects involved in improving geothermal drilling technology. Other recent and ongoing GDO projects include:

- **High-Temperature Drill Pipe Protectors**, Regal International, Brookhaven National Laboratory, and Unocal.
- **Retrievable Whipstock**, Smith International and Unocal.
- **Downhole Air Motor**, Baker Hughes Inteq and Unocal.
- **Cementitious LCM Field Evaluation**, Halliburton Services and CalEnergy.
- **Downhole Mud Hammer**, Novatek, Unocal, and CalEnergy.
- **Expert System for Lost Circulation Control**, Tracor Inc. and CalEnergy.

PROGRESS IN DEVELOPING CORROSION- AND SCALE- RESISTANT MATERIALS

Significant cost reductions in geothermal technology are highly dependent on the development of materials that reduce corrosion and scale deposition and increase the durability of lightweight cements for well completions. The presence of carbon dioxide in geothermal fluids is causing cement failures to occur in less than five years and, in one case, has resulted in a collapsed casing within 90 days. In binary plants, corrosion prevention can require use of high-alloy steel tubes for the heat exchangers, which increases the cost. Even then, excessive fouling prevents the economic use of binary processes with hypersaline brines.

High-alloy steels are cost prohibitive for most geothermal plants, and the current practice is to attempt to minimize corrosion and the rate of scale deposition through better plant design that optimizes energy

conversion and fluid injection operations. The Geothermal Material Program at Brookhaven National Laboratory (BNL) has made significant advances in some of these problem areas.

Research at BNL has produced phosphate-modified calcium aluminate compounds that yield high-strength, CO₂-resistant cements that are pumpable over a wide range of temperatures. By further incorporating hollow microsphere fillers into this matrix, BNL produced a lightweight cement slurry that cures to yield strength and durability properties suitable for well completions. As an example, the inclusion of chemically inert acrylonitrile polymer microspheres produced a slurry with a density of 1 g/cc. After autoclave exposure to a 0.05M sodium carbonate solution at 250°C (482°F) for six months, the cement retained 73 percent of its initial strength.

Compared to the above cement formulations, cost reductions of approximately 70 percent can be made by blending Class F flyash with the calcium aluminate cement. This formulation is also resistant to CO₂ attack. After 28 days in a 4.0 percent by weight sodium carbonate environment (15,700 ppm CO₂) at 300°C (572°F), no signs of alkali carbonation-caused damage were apparent.

Field testing of a polymer concrete-lined carbon steel tube in flowing hypersaline brine under heat exchange conditions verified the hydrothermal stability and corrosion protection capabilities of the liner. Heat transfer and fouling coefficients similar to those for the high-alloy steel (AL-6XN) control tubes were measured. Based on these results, it can be concluded that the high-temperature polymer used as a matrix for the PCL is an excellent candidate for use as a corrosion-resistant coating for pipelines and other process components.

BNL is also evaluating methods for the field

application of polymeric and ceramic coatings to geothermal process components. It demonstrated that a high quality polyphenylene (PPS) coating can be produced using flame spray techniques.

STUDY EVALUATES NEXT GENERATION GEOTHERMAL POWER PLANTS

A recent study co-sponsored by the U.S. Department of Energy, Southern California Edison, and the Bonneville Power Administration examined commercial binary and flash geothermal power generation technologies and compared them to advanced concepts proposed for the next generation of geothermal power plants. The study, "Next Generation Geothermal Power Plants," analyzed and compared the performance, capital cost, cost of power, and environmental impact of the different concepts. The study was managed by the Electric Power Research Institute (EPRI), with the CE Holt Company as the prime contractor, and Fuji Electric Company and Barber-Nichols Engineering as subcontractors.

The study concluded that none of the technologies constitutes a real breakthrough. The next generation geothermal power plant concept may improve brine utilization but is unlikely to reduce the cost of power generation by much more than 10 percent. Lower temperature resources will benefit more from the development of a next generation geothermal power plant than will hotter resources.

The advanced concepts studied included advanced binary and flash plants, flash/binary hybrid plants, and fossil/geothermal hybrid plants. The concepts were developed into viable power

plant processes, capital costs were determined, and levelized busbar costs were calculated using resource characteristics at 10 different geothermal sites located in the western United States. Therefore, the results should serve as useful indicators of the commercial viability of the various concepts investigated.

The following advanced concepts were found to be promising for some of the sites:

- The use of mixed working fluids for binary plants. This, particularly, is a low-risk option.
- A rotary separator turbine, upstream of a dual flash turbine. This could be beneficial at high-temperature resources where pressures differ significantly from well to well, e.g., the Salton Sea.
- Using hot water turbines to recover additional energy from spent brines in a dual flash plant.
- A hybrid of gas combustion turbine and geothermal binary. This would be an economic option for the lowest temperature sites if natural gas prices remain low.
- A synchronous turbine option proposed for binary plants. But this requires prototype testing.
- Dual flash binary bottoming cycles would be promising if fouling of the heat exchangers is controllable.

The study further concluded that metastable expansions, steam reheaters, sub-atmospheric steam flash, dual flash backpressure turbine, and hot dry rock concepts do not seem to offer any cost or technical advantage.

To order the report, contact EPRI at (510) 934-4212 and reference report number EPRI TR-106223.

COMMERCIAL DEMONSTRATION OF SUPERSATURATED TURBINE EXPANSIONS

The long-term effects of supersaturated expansions on the performance of binary cycle turbines were successfully evaluated during a year-long demonstration at an operating commercial geothermal power plant. Test results matched those of short-term investigations at the Idaho National Engineering and Environmental Laboratory (INEEL) which indicated that if supersaturated expansions proceed without forming condensates, improvements in cycle performance could be achieved. (See Geothermal Progress Monitor No. 17.)

In November 1995, a six-month study began with the installation of a new rotor and set of vanes on the turbine of the Mammoth Pacific Limited Partnership (MPLP) MPI-100 binary facility near Mammoth, California. Once operation of the facility resumed, the turbine inlet conditions were adjusted to allow the isobutane vapor to pass through the two-phase region producing the desired metastable expansions. The modified and typical turbine inlet conditions are depicted on the temperature-entropy (T-s) plot in Figure 8. The dashed constant entropy lines depict an ideal expansion process in the turbine (the isobutane expansion through the turbine nozzles approaches this ideal process).

The MP1-100 turbine operated with the metastable expansions through May 1996 without any measured degradation in efficiency. At that time, MPLP and INEEL mutually agreed to continue operating the turbine with these expansions until the fall of 1996 to provide approximately one year of operating data. With the consent of MPLP, INEEL investigators periodically increased the degree of supersaturation (extent to which the expansions enter the

two-phase region) in the expansions. The normal maximum equilibrium moisture content in the metastable expansions during the investigation was five percent, although during a portion of the operation moisture contents of up to seven percent were present.

During the period between March and May 1996, the data acquisition system at the MP1 facilities was not operating, and data were not available. During this interval the MP1-100 facility continued to operate with the metastable expansions, using readings from non-recording indicators and gauges to monitor the turbine operation. When the data acquisition system operation resumed in May, the efficiencies were slightly lower and there was more variation in the values. The scatter, or variation in the turbine efficiencies, was due in part to fluctuation in the ambient air temperature (and turbine exhaust pressure). Figure 6 shows the efficiency trend with the ambient air temperature.

Mammoth's MP1 facility consists of two identical, and independently-operated binary power plants. While the MP1-100 plant was operated with the metastable expansions, the MP1-200 plant was operated in a mode used by MPLP at the remainder of its facilities (sufficient superheat at the turbine inlet to assure the turbine expansions remain completely outside of the two-phase region). During this period, both plants were operated at approximately the same brine flow rates.

The ratio of brine effectiveness for the two plants plotted with time is shown in Figure 7. These data show that the MP1-100 plant was consistently producing from 15 to 35 percent more power from an equivalent brine flow. Throughout the investigation, MP1-100 produced more power than the MP1-200 plant. Given that the parasitic power requirements for the two plants are roughly equivalent, the MP1-100 unit was consistently producing

Figure 6. Impact of Ambient Temperature on MP1-100 Turbine Performance

Figure 7. Comparison of Performance of MP1-100 and MP1-200 Power Plants

approximately 500 kWe more electricity for sale throughout the investigation. During the next plant shutdown, probably in the spring of 1997, the condition of the turbine rotor and vanes will be examined.

Given the success of the investigation, INEEL researchers will be contacting operators of other candidate binary facilities to solicit interest in the use of metastable turbine expansions.

PLANNED GEOTHERMAL ENERGY FACILITY RECEIVES INDUSTRY ENDORSEMENT

The planned construction of a Geothermal Energy Conversion Facility (GECF) at the National Renewable Energy Laboratory (NREL), the purposes of which were described in Geothermal Progress Monitor No. 17, has received considerable interest from private industry. A number of utilities and geothermal power producers have expressed support for an in-house NREL capability to evaluate innovative thermodynamic processes suitable for binary plants because of the limitations imposed on schedule and process conditions by experimental work at commercial sites.

A recent Octane Week article entitled "Fouling and Heat Transfer R&D Boosts Current Plant Efficiency" indicated that the NREL work will aid industrial processes using mixed working fluids such as the Organic Rankine Cycle which uses hydrocarbon mixtures.

The benefits of the GECF may extend beyond geothermal applications as evidenced by the interest expressed by such programs as the "Refineries of the Future," a collaborative program between DOE national laboratories and the U.S.

petroleum refining industry. Refineries face problems with fouling of heat exchangers, similar to those at geothermal power plants, resulting from boiling and condensation of two-phase, mixed-composition working fluids.

The GECF will initially use mixtures of hydrocarbons such as isobutane, pentane, isopentane, heptane, and hexane. These working fluids will be heated by a secondary hot water loop with a capacity of approximately 600 kW. The loop design will allow the working fluid to vaporize at supercritical or subcritical pressures as high as 700 psia. No turbine will be installed. A bypass valve will be used instead. After exiting the bypass valve, the working fluid will condense by passing through a heat rejection unit. The components and piping of the heat rejection system unit will be arranged and designed to permit both wet and dry cooling in series, parallel, or as stand alone operations. A cooling tower will be used for wet cooling.

The GECF will employ numerous probes to measure the pressure, temperature, and flow rate of each fluid entering and leaving each piece of equipment. Proper design considerations have been taken for future installation and testing of an appropriate size turbine. As part of the development process, researchers and representatives of the NREL's Environmental, Safety, and Health Branch are conducting a detailed risk assessment to identify all possible hazardous scenarios that might be faced in the operation of the facility. Construction of the GECF should be completed by May 1997.

FULL-SCALE BIPHASE GEOTHERMAL TURBINE READIED FOR TEST AT CERRO PRIETO

Based on the successful results obtained from a DOE-sponsored test of a sub-scale Biphase geothermal turbine, at Coso, California, a full-scale Biphase Model 30RS13 has been manufactured for demonstration tests at Cerro Prieto, Mexico (see Figure 8). This turbine will generate power from mixtures of steam and brine and will be assembled and integrated with a backpressure steam turbine as a wellhead system. It will commence operation in early 1997, delivering 1 MWe at the wellhead and supplying the exhaust steam to the backpressure turbine generating 3 more MWe and finally to the existing central power plant where it will be used to produce an additional 7 MWe. The total installed cost of the system is approximately \$2.69 million, at a capital cost of \$678 per kilowatt which compares favorably with conventional geothermal

flash plants that cost \$1,000/kW to \$1,500/kW. Douglas Energy, the turbine manufacturer, has contracted to sell the electricity produced during the demonstration to CFE at 4.2 cents/kWh. Additional plants of the same type are envisioned in Mexico.

An earlier Biphase unit was demonstrated for 4,000 hours in the 1970s at Roosevelt Hot Springs, Utah. The unit generated 1,600 kWe and demonstrated a 20 percent increase in power output above that of a single flash turbine with the same brine flow. An Application and Economic Study was conducted as part of a DOE project to determine whether a viable U.S. Biphase turbine manufacturing business for domestic use and exports will develop. Results indicated that Biphase topping power plants, costing \$500 to \$750 per kW, can be built and operated at a profit in Mexico, the Philippines, and Indonesia. Near-term marketability was considered in terms of applying the Biphase units to existing geothermal projects.

The economics of producing 100 MWe were analyzed using fluid from a group of

Figure 8. Rotor of Biphase Turbine Model 30RSB

existing wells at Cerro Prieto. Approximately half of these wells have sufficient pressure to incorporate both a back-pressure turbine and a Biphase unit, which significantly improves power output from the high-enthalpy wells. Results from the analysis indicate that a 100-MWe project is commercially viable and would be able to sell electricity at 3.7 cents per kWh. A similar study conducted by the Philippine National Oil Company (PNOC) showed that an additional 100 MWe could be produced from 33 wells at an estimated capital cost of \$495/kW.

In the future, the Biphase turbine could be used in new projects. There appears to be a market in developing countries for stand-alone wellhead units which could operate with atmospheric discharge to serve remote communities. The Biphase turbine can also operate as a bottoming unit using the hot water from steam separators. A study at the 20-MWe Blundell plant in Utah showed that an additional 9 MWe could be generated from such a bottoming cycle. The additional power produced from topping or bottoming Biphase plants imposes no environmental impact.

STATE AND LOCAL

CALIFORNIA ENACTS LEGISLATION TO DEREGULATE ELECTRIC MARKETS

In September of 1996, California enacted legislation governing the state's transition to a more competitive electricity market. The law, AB 1890, seeks to ensure a smooth transition to a more competitive market structure while preserving the reliability of the system, protecting consumers, and continuing California's commitment to developing diverse, environmentally-sensitive electricity resources. The comprehensive legislation covers five key elements:

- Stranded cost recovery
- Organization of a new industry structure
- System reliability
- Funding of public purpose and environmental programs
- Consumer protection.

The act provides for accelerated recovery of stranded costs, referred to in the act as "transition costs." Electricity rates charged to all customers will include a "competition transition charge" to allow utilities to recover the outstanding cost of assets covered under the present rate structure.

To provide the new industry structure, the act creates two state chartered, nonprofit institutions, an independent system operator (ISO), a Power Exchange, and an Oversight Board to govern the two. The ISO will operate the transmission grid to ensure its efficiency and reliability. The Power Exchange will operate an "efficient,

competitive auction" for the buying and selling of electricity. The Oversight Board will consist of three California electricity ratepayers appointed by the governor, one non-voting member of the Senate, and one non-voting member of the Assembly. The Oversight Board will appoint governing boards for the ISO and Power Exchange.

Ensuring continuing system reliability is the responsibility of the ISO. This will be done in coordination with the Western Area Coordinating Council and the North American Electric Reliability Council.

The act continues funding for low-income electricity customers, including energy efficiency services and the California Alternative Rates for Energy Program. The act includes provisions for the funding of three environmentally-related programs for a four year period beginning 1/1/1998:

- Renewable Energy - The state's three investor-owned utilities (IOU) will fund existing and new renewable energy technology and related programs at \$540 million. The California Energy Commission will administer the fund.
- The IOUs will also pay \$872 million for energy efficiency and conservation activities and programs. The fund will be administered by the California Public Utility Commission (CPUC).
- The IOUs will pay an additional \$250 million for research, development and demonstration programs that are not adequately provided by competitive and regulated markets. The fund will be administered by the CPUC.

The act charges the CPUC with continued responsibility to protect electricity consumers. This includes registration of retail electricity service providers and handling consumer complaints.

CALIFORNIA ENERGY COMMISSION SOLICITS PROPOSALS FOR INTERNATIONAL SUPPORT AND WORKSHOP ON EL SALVADOR

The California Energy Commission's International Energy Fund was established to assist California-based firms to perform preconstruction activities leading to exports of technology and services for power plant and energy-related installations in foreign nations. This year marks the eighth solicitation under CEC's Energy Technology Export Program for which \$250,000 in funding was allocated, half of which has already been awarded.

Prior to the formal solicitation period, September 30 through October 4, two workshops were conducted in Santa Monica and San Francisco to inform applicants about procedures and types of projects entertained. Final proposals were due by November 26 and applicants will be notified of evaluation results in February 1997. Final awards are expected to be made in March, 1997.

Preconstruction activities include, but are not limited to: market analysis, feasibility studies, resource assessments, site analysis, bid and/or proposal development, and establishment of technology transfer agreements. They may also include efforts to encourage private financing and foreign ownership of projects.

Meanwhile, CEC announced a public workshop to be held January 15, 1997, in

San Francisco on geothermal opportunities in El Salvador. The opportunities are enhanced by recently enacted legislation to privatize the country's governmental-run enterprises. Its geothermal resources are estimated at 3,000 MWe.

CEC SEEKS PARTNERS FROM INDUSTRY FOR DOE VENTURES FUNDING

In July 1996, the California Energy Commission (CEC) sought applications from those in industry interested in partnering with the Commission in applying for federal funds under DOE's Commercialization Ventures Program. Such a partnership, between a state energy office and industry, is required to be eligible for the federal funds. At least 50 percent of total project cost must be provided in the form of non-federal funds by project participants. This cost sharing may be in the form of cash or in-kind contributions such as labor or use of equipment.

The CEC Request for Applications No. 500-96-504 noted that the Commission had identified funds from the Geothermal Resources Development Assistance (GRDA) Program as a possible source for matching funds, if the proposed project qualified under program requirements. DOE is expected to have approximately \$8-11 million available and anticipates making 5 to 10 awards nationwide for projects that will accelerate the commercialization of emerging renewable energy technologies. An emerging technology is defined as one that has already proven to be technically viable (i.e., it works), but which has had little or no operational track record. It can also include an innovative application of an emerging technology that has not been generally utilized (i.e., where experience has been limited to sub-commercial sizes or quantities and/or been restricted or

controlled to limited applications).

Proposals from industry to CEC were due on August 19, notice of selection of the joint applicant were expected on August 23, and the joint application to DOE was due on August 29, 1996. Two industry proposals were received. One did not meet the requirements and was rejected by the Commission. The other, sent to DOE, was funded.

CEC BEGINS NEW FUNDING CYCLE FOR GEOTHERMAL PROJECTS; \$3.7 MILLION AVAILABLE

The California Energy Commission announced the beginning of a new funding cycle to private for-profit and public entities engaged in the development of new geothermal resources and technologies. Practically all aspects of geothermal research, resource development, commercialization, planning, and impact mitigation are eligible for funding. Recent approvals by the Energy Commission have been to fund research, development, demonstration, and commercialization projects rather than planning or mitigation projects. To qualify, the project must directly relate to geothermal energy and be located in California or be sponsored by a California-based company. All projects must have a hardware component (e.g., well drilling; resource assessments; small-scale electricity production; direct-use systems; or testing or demonstration of innovative geothermal assessment techniques, components, or systems).

Approximately \$3.7 million is available for the fiscal year 1996-97, which ends on June 30, 1997, and approximately \$2.6 million of the \$3.7 million will be available until June 30, 1998. A matching contribution is required. The November 8

notice also advised that the application Manual has been revised. A new Application Manual may be obtained by calling (916) 654-5129.

GEOTHERMAL POTENTIAL IN NEW YORK ASSESSED

The New York State Energy Research and Development Authority (NYSERDA) and the US Department of Energy commissioned a study of New York state's potential for geothermal power generation. Similar studies previously conducted had become dated, and NYSERDA wished to evaluate the potential for developing the state's resources with current technology, which is much improved over that considered in previous studies.

The study included a new resource assessment conducted by the State University of New York at Buffalo, based on existing data. The resource assessment identified a potential geothermal power generation site near Elmira, New York. The 130°C resource is in the Theresa geologic formation at a depth of about 10,000 feet.

Lynn McLarty of and Gene Beeland of DynCorp, Virginia, Information and Engineering Technology (now at Princeton Economic Research, Inc., Maryland) conducted the remainder of the study, consisting of a geothermal technology characterization, an economic evaluation for a hypothetical plant, and an assessment of the environmental impacts associated with potential geothermal power generation development in the state. The economic evaluation was based on the resource assessment. A binary plant was appropriately designed for the target resource, and an economic model was created to perform a life-cycle cost analysis for the plant and well field. The

hypothetical plant was designed as a 5 MWe modular unit up to 15 MWe, this being the maximum capacity the reservoir would support for a given area. The life cycle cost analysis suggested that the

electricity produced, using currently commercial technology, would probably cost between 14 and 18 ¢/kwh as shown in Table 2.

Table 2. HOT DRY ROCK COST ESTIMATES							
Plant Size net MW	Power Plant Costs (excludes transmission line costs)			Well Field Costs			
	Capital	O&M		Capital	O&M		Levelized Cost
	Total Cost \$k	Variable mills/ kWh	Fixed \$/kW-yr	Total Cost \$k	Variable mills/ kWh	Fixed \$/kW-yr	Constant 1995\$ ¢/kWh
5	9,408	2.7	47	41,448	2.96	52	18.4
10	18,816	2.7	47	65,199	2.33	41	15.9
15	28,223	2.7	47	85,911	2.04	36	14.8

COLORADO AQUAFARM WILL BE TRAINING LABORATORY

An agreement has been signed by the Colorado Board of Community Colleges and Occupational Education and the owner of Kerr's Aquafarm under which the geothermal fishery will be used for instructional and production purposes in a new aquaculture training program. The new program will be offered by the San Luis Valley Educational Center at the Alamosa Campus of Trinidad State Junior College. Students may enroll for a two-year Associate of Applied Science degree or a one-year Occupational Certificate.

Upon completion of the program, students will be able to perform the duties and responsibilities of propagating, feeding, caring, transferring, harvesting, and sales of fish and other aquaculture products. Kerr's Aquafarm will provide the program with an excellent opportunity to introduce technology and train students in the various types of culture, practices, and techniques currently employed in the industry. The Aquafarm has 30 acres of existing ponds, raceways, tanks, and a greenhouse. A geothermal well supplies 36°C (97°F) water year round.

Source: Aquaculture News 9/96

GEOHERMAL SPRINGS SUPPLY ALLIGATOR FARM

For nearly 20 years, Mr. Leo Ray of Buhl, Idaho, has been using geothermal springs to provide warm 29°C (85°F) water to raise fish. His operation has served as a model for numerous other geothermal fish farmers in the western U.S. Mr. Ray started out with catfish, adding tilapia a few years later. He sells his farm-raised fish to haute cuisine restaurants throughout the West. Recently, Mr. Ray has added alligators to his operation. He buys six-inch alligators and raises them under a controlled-temperature environment for optimum growth. When they are several feet long, he sells the hides (worth \$100 each) as well as the meat, which is much in demand.

AUSTRALIAN LOBSTERS RAISED AT BELMONT HOT SPRINGS, UTAH

The Belmont Hot Springs, north of Salt Lake City in Utah, supply 4,000 gpm of 46°C (115°F) hot water to heat aquaculture ponds, a swimming pool, hot tubs, and four homes.

At the aquaculture facility, Red Claw Lobsters are raised in a total of 30 ponds and a three-quarter mile long channel 50 feet wide and 10 feet deep. The water in the ponds and channel is maintained at 27°C (80°F). The lobsters are harvested when reaching lengths between one-fourth inch to 9 inches and shipped live to various markets. Tropical fish are also raised.

Also, the hot springs supply water to a 200,000-gallon swimming pool and three hot tubs. Four homes use some of the geothermal water in a radiant-floor heating system. A unique application at one of the springs, which is 35 feet deep with 83°C (92°F) waters, is scuba diving from September through May. The spring is too hot to use for diving during the summer months.

The owner and operator of the facility is Scott Holmgren, Belmont Hot Springs, Box 36, Fielding, UT 84311. Phone: 801-458-3200.

Source: Geo-Heat Center Quarterly Progress Report 1, 3/96

 

INTERNATIONAL

CALENERGY AND UNOCAL CONTINUE SUCCESSES OVERSEAS

CalEnergy Company and Unocal Geothermal are continuing their successful efforts on geothermal power projects in the Philippines and Indonesia. CalEnergy recently completed a plant in the Philippines and has two additional plants under construction there, as well as one under construction in Indonesia. Unocal continues to provide steam for a number of plants in the Philippines, is constructing three new plants at one site in Indonesia, and is conducting exploration at another Indonesian site.

In mid-1996, CalEnergy completed the 125 MW Upper Mahiao geothermal power plant on the island of Leyte, in the Philippines. The plant was built under a Build-Own-Operate-Transfer (BOOT) contract with a CalEnergy subsidiary as owner. The plant was designed and constructed by Ormat, using both Ormat and General Electric turbine generators. The power is sold to PNOC-Energy Development Corporation, part of the state owned oil company. This is currently the world's largest combined flash and binary plant, as well as the world's largest geothermal plant using air cooled condensers.

CalEnergy is also currently constructing the three unit, 216 MW Malitbog geothermal flash plant in the Philippines (Figure 9).

One unit is complete, and the other two should be completed by summer of 1997. The third CalEnergy project in the Philippines, the 164 MW Mahanagdong plant, is under construction and is to be completed by mid 1997. The total capacity of the three projects is over 500 MW. Resource development for all three of the projects is the responsibility of the Philippine National Oil Company.

In Indonesia, CalEnergy has begun construction of the first 55 MW plant at Dieng, in Central Java. The target completion date for the plant is around the end of 1997 or early 1998. The Dieng contract allows for development of up to 400 MW, depending on the capacity of the resource. CalEnergy has similar contracts at Patuha and Bali geothermal sites in Indonesia.

Unocal is constructing three 55 MW units at Gunung Salak, Indonesia. These are expected to be operational by mid-1997. Unocal already supplies steam for two 55 MW units there, owned by PLN, the state utility, which is also building a third 55 MW unit. Unocal will own and operate the three plants it is constructing, as well as supply steam for all six of the plants. Unocal also has a contract to develop up to 1,000 MW at Sarulla, Indonesia. Exploration activity there is underway.

Sources: CalEnergy and Unocal U.S. Security and Exchange Commission filings, and Forte paper in 1996 Geothermal Resources Council Transactions.

Figure 9. Portion of CalEnergy's Malitbog, Philippines, Geothermal Project

IEA INITIATES COLLABORATIVE GEOTHERMAL R&D

The International Energy Agency (IEA), an arm of the Organization of Economic Cooperation and Development (OECD), has initiated a new collaborative program in renewable energy with a geothermal component. Thus far, eight geothermal tasks, identified by individual member countries and national organizations, have been included by the IEA:

- I: Environmental Impacts of Geothermal Energy Development; led by New Zealand
- II: Shallow Geothermal Resources and Heat Pumps (lead country being sought)
- III: Hot Dry Rock; led by Japan

- IV: Deep Geothermal Resources; led by Japan
- V: Sustainability of Geothermal Energy Utilization; led by U.S.A
- VI: Geothermal Power Generation Cycles; led by Italy
- VII: Geochemistry of Geothermal Fluids (lead country being sought)
- VIII: Low-Enthalpy Geothermal Resources for Industrial Processes; led by Italy.

The activities for these tasks are mostly collaborative, such as organizing sessions at international, national, and special geothermal congresses, conferences, workshops, and other forms of interactions between scientists, engineers and geothermists.

The implementing agreement being developed by IEA and participating organizations (organizing agents or O.A.s) encompasses a task-shared approach to funding. Under the agreement, the participants in the topical areas would contribute the personnel, facilities, resources, and other support needed for each project. The agreement does not involve any contributions of money to any common budget or fund.

For each country, a leader will be appointed to develop a work plan and recruit participants, an effort supported by the O.A. in charge. Participants can be from universities, national laboratories or institutes, commercial firms, alliances, professional and trade associations, consortia, and other organizations engaged in research or technology development in geothermal energy. To illustrate, one principal goal of the O.A. task and project leaders is to organize special sessions at major geothermal conferences, such as topical sessions at the World Geothermal Congress 2000 to be held in Japan in the year 2000.

Source: GRC Bulletin 7/96

MORE INTERNATIONAL CONTRACTS FOR U.S. FIRMS

Amoseas Indonesia, a jointly held affiliate of Chevron and Texaco, was awarded a contract to construct a 70 MWe power plant in Darajat, western Java. Amoseas and its partner, PT Prasarana Nusantara Jaya (PNJ), will invest approximately \$125 million in the new plant. The contract, awarded by the state-owned electric utility (PLN) and Pertamina, also allows for additional development at Darajat, which could result in as much as 275 MW of electricity and the construction of up to

three additional power plants.

Calpine Corporation entered into a joint venture agreement with PT Dharmasatrya Arthasentosa (DARTA) to develop geothermal facilities in Lampung Province. The projects will be developed at the Ulubelu field and will target 330 MWe of capacity. The initial 110 MWe plant is expected to be commissioned in the year 2000 and will sell its output to PLN.

Calpine also signed an agreement with Constructora y Perforadora Latina, S.A. de C.V. (Coperlasa) to participate in a 160 MWe geothermal production contract at the Cerro Prieto field in Baja California, Mexico. The contract is between Coperlasa and the Mexican utility CFE. Calpine will invest \$18.5 million, structured as a senior secured loan to Coperlasa, and will receive fees for technical services provided to the project. Loan proceeds will be used to fund drilling of new geothermal wells to serve the 160 MWe plant. Calpine will also pay \$1.5 million to acquire an option to purchase a 29 percent equity interest in Coperlasa. Mexican banks will lend an additional \$4 million to the project.

Source: GRC Bulletin 12/95, 1/96, 4/96

WORKSHOP PROMOTES U.S. INTEREST IN MEXICAN GEOTHERMAL DEVELOPMENT

A workshop was held in June 1996 in Morelia, Mexico, designed to bring together those interested in working with the Comision Federal de Electricidad (CFE), Mexico's government-owned electric power utility and other Mexican government agencies to develop geothermal resources. The workshop was co-sponsored by CFE, the Geothermal Resources Council, and the Geothermal Energy Association.

The workshop sponsors noted that in the past year the Mexican government has made several significant changes in its laws and regulations concerning the development of natural resources. The workshop was developed to discuss and help attendees better understand the effects these changes will have on future geothermal development in Mexico. Presentations covered the legal and regulatory framework, independent power development, joint venture opportunities, updates on Mexican geothermal projects, and CFE's involvement overseas, and requirements for financing geothermal development by various financial organizations. Workshop participants included Mexicans who process project applications, provide technical expertise, arrange for financing, regulate operations, and oversee projects as well as Americans from both industry and government.

INDONESIA IS "HOTTEST SPOT" FOR GEOTHERMAL DEVELOPMENT

Indonesia's economic boom has prompted a surge in the demand for electricity, creating opportunities to develop its extensive geothermal resources. The government of Indonesia promotes the use of geothermal energy in recognition of the environmental benefits of this indigenous resource and its role as a substitute for oil.

The demand for power, economic boom, resource availability, and government support make Indonesia the "hottest" spot on earth for the development of geothermal energy, according to Darcel Hulse of Unocal.

Speaking to the Indonesian Petroleum Association's 24th Annual Convention in October 1995, Hulse noted that "the high

heat flow resulting from recent volcanism and crustal intrusion has led to the development of both magmatic and meteoric hydrothermal systems. The tectonically-active nature of the Indonesian Islands has also led to the development of fracture networks in the reservoir rocks promoting the enhanced permeability which allows for large-scale fluid flow."

At present, 70 high temperature geothermal areas have been identified in Indonesia. Most of these prospects are located on the islands of Java, Sumatra, and Sulawesi, where additional electric power is needed. Pertamina, the national oil company, estimates a geothermal resource potential equivalent to 19,000 MW of electric power. Assuming a reservoir life of 30 years and an operating load of 80 percent, this potential is equivalent to 1.81 billion tons of coal or 6 billion barrels of oil.

At its current rate of growth, the economy of Indonesia will double every 10 years. If the demand for energy matches the growth rate, the total energy consumption will increase from the 1993 level of 450 million barrels of oil equivalent (BOE) to 2.04 billion BOE by 2018. Other factors that favor growth in geothermal development include:

- Indonesia's transition from a resource-based to a manufacturing-based economy, which stimulates greater demand for electric power.
- The lack of a major inter-island transmission system discourages construction of large central generating stations.
- Incremental capacity demands tend to be relatively small (25 to 200MW).

Hulse also noted that indigenous geothermal energy provides both environmental and economic benefits.

With its use, Indonesia's coal and oil reserves can be exported, favorably impacting the gross domestic product.

The only potential impediment Hulse foresees in the future of geothermal energy in Indonesia is the obligation placed on PLN, the state utility, to become the low-cost provider of electric power. "The least cost option today may not be the least-cost option tomorrow, and the least cost to PLN may not be the best for the long-term economic growth of the country," he observed. Hulse concluded his speech by noting "PLN must be expected and encouraged to be an implementer of the national energy policy in determining the fuel mix for electricity generation. If this is done, geothermal energy will play a vital role in Indonesia's economic development, and Indonesia will become the world's leading producer of geothermal energy.

Source: GRC Bulletin 1/96

PACIFIC ISLANDS SHOW INTEREST IN GEOTHERMAL POTENTIAL

A report prepared for the South Pacific Applied Geoscience Commission (SOPAC) indicates that the potential for using geothermal resources exists within the five island nations of Fiji, Vanuatu, Papua New Guinea (PNG), Solomon Islands, and Western Samoa. All five countries are interested in developing their resources.

The availability of small modular binary cycle units suitable for moderate temperatures and modest power requirements adds to the attraction of geothermal power. The small, growing industries associated with primary production, such as sugar refining in Fiji, can benefit from geothermal energy. Other direct uses of geothermal energy can be

expected and have been considered in some of these countries. Salt production is under consideration in Vanatu and a number of agro-industrial applications in PNG, such as copra and cocoa drying and palm oil processing. Geothermal energy could conserve the biomass and fossil fuels currently being used.

Small geothermal developments would benefit the economies of the nations. Imported fossil fuel costs could be reduced, and small-scale industries could be expanded to produce export revenue. In addition, the island nations could reduce combustion-related gas emissions and enjoy the benefits of an environmentally friendly energy resource to the maximum.

The report was prepared by Geothermal Energy New Zealand Limited (GENZL) with financial assistance from the government of New Zealand.

Source: GRC Bulletin 2/96

CHINA SYMPOSIUM SPOTLIGHTS ASIAN GEOTHERMAL POTENTIAL

An International Symposium on Geothermal Energy Development and Utilization was held in Kunming City, Yunnan Province, in Southwestern China on April 23-29, 1996. The symposium was jointly organized by the Yunnan Provincial Science and Technology Commission and the Chinese Geothermal Commission. The event was sponsored by the Chinese State Science and Technology Commission and by the United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP). Approximately 40 geothermal specialists attended the symposium, roughly half from China and the rest representing 12 countries: India, Indonesia, Israel, Japan, Malaysia, Myanmar, New

Zealand, Pakistan, the Philippines, Thailand, the United States, and Vietnam.

The symposium focused on ways of promoting the beneficial uses of geothermal energy in the developing countries of Asia in general and southwestern China in particular. Chinese attendees presented several papers on the Rehai (Hot Sea) geothermal field near the city of Tengchong in Yunnan Province, close to the China-Myanmar border. China is upgrading highways into this scenic mountainous area to access geothermal resources that could support an expanding regional power market. Geochemical tests on fluid samples from hot springs in the Rehai field suggest reservoir temperatures in the range of 230-275°C (445-525°F). The productive potential of the field has also been estimated by calometric methods to be about 23 MWe for 30 years.

During a three-day field trip to the Tengchong area, Chinese government officials stressed that they encourage private investment and indicated that investors could expect to receive good returns from geothermal projects.

For more information, interested parties may contact either of the following:

- **Professor Lin Wenlan**, Director General
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Technology Commission
110 Beijing Road, Kunming, Yunnan
People's Republic of China
Tel: 86-871-3188 984
Fax: 86-871-3136 444
- **Dr. Kyi Lwin**, Economic Affairs Officer
Environment and Natural Resources
Management Division (ESCAP)
U.N. Building, Rajpamnern Avenue
Bangkok 10200, Thailand
Tel: 66-2-7881529
Fax: 66-2-2881000 or 2881059.

Source: GRC Bulletin 7/96

INTEREST IN GEOTHERMAL ENERGY REVIVES IN CHILE AND COLOMBIA

According to Miguel Munoz of the University of Chile, the decade-long period of indifference toward geothermal energy in Chile is attributed to difficulties in the assessment of the resources and the lack of a legal framework for development. Geothermal studies were carried out in northern Chile between 1967 and 1975, mainly in the El Tatio field. The maximum measured temperatures varied between 211°C (412°F) and 257°C (515°F), with an estimated electrical potential of 100 MW. Resource temperature surveys have also been done in the north, where geothermal power projects are expected to be concentrated, as well as in the central-southern regions. The latter are more appealing to rural electrification projects. Direct use projects in central Chile will also benefit from the low-enthalpy resources. Legislation governing exploration, development, and commercial and industrial uses of geothermal energy is in process. Several national and foreign groups are interested in exploring and developing the resource.

Colombia's resources have been studied by several organizations including CHEC, an electric utility, the Instituto Colombiano de Energia Electrica (ICEL), the Organizacion Latinoamericana de Energia (OLADE), and the Italian national utility ENEL. Geothermal reconnaissance studies and rankings of potential development areas were conducted in the early 1980s, including prefeasibility studies of the Macizo Volcanico del Ruiz. In 1985, a catastrophic volcano eruption interrupted geothermal efforts for several years. In 1992, Geoenergia Andina SA (GESA) was established with interests in developing the country's geothermal resources. GESA conducted feasibility studies at the Las Nereidas geothermal field which has been

selected as the site for the first deep exploration well in the country. This first well is expected to be a 6,600 feet (2,000 meters) deep slimhole.

Source : IGA News 1-3/96

MEXICO'S CFE WILL MONITOR COSTA RICA'S MIRAVALLES FIELD

Mexico's Comision Federal de Electricidad (CFE) signed an agreement with Costa Rica's Instituto Costarricense de Electricidad (ICE) to monitor two wells at the Miravalles geothermal field for two years. The wells are being monitored under actual operating conditions and will serve two 5 MWe backpressure turbines to be brought from Los Azufres in Mexico.

Joint ICE-CFE studies will focus on: 1) possible scaling problems in the steam gathering and injection systems; 2) wellhead pressure and production decline; and 3) movement of the injected fluids and their impact on field performance. The project will enable a better understanding of the reservoir's behavior under production and injection conditions. The electricity produced will be delivered to the distribution grid. CFE will cover the costs of the study and other related expenses from the revenues generated.

Source: IGA News 1-3/96

VIETNAM EVALUATES ITS GEOTHERMAL RESOURCES

Vietnam is tectonically situated on the marginal contact between the East Sea Basin and the Indochina continental ridge. More than 300 hot springs have been discovered with temperatures ranging from 30°C (86°F) to 105°C (220°F). Six prospective areas have been identified for development based on tectonic activity and geographical economic zoning. These areas have yet to be carefully examined and evaluated to define the geothermal potential and develop conceptual models of reservoir structure, size, and depth. Depending on site-specific outcomes, electricity generation and/or direct use applications are being considered.

The geology of the six regions is described in a paper by the Vietnam Research Institute of Geology and Mineral Resources in the February 1996 issue of the Geothermal Resources Council Bulletin.

TECHNOLOGY TRANSFER

DOE INAUGURATES GEOTHERMAL TECHNOLOGIES NEWSLETTER

DOE inaugurated its new "Geothermal Technologies" newsletter in the July 1996 issue of the Geothermal Resources Council Bulletin. It will appear quarterly, providing current information about the activities of the geothermal program, recent research and development findings, and future plans that can benefit the U.S. geothermal community. Articles and announcements will help communicate opportunities to participate in the program and help find ways for joint DOE-industry projects.

The inaugural newsletter announced four new geothermal research activities selected for immediate funding. The Office of Geothermal Technologies committed approximately \$500,000 held in reserve from current year funds. The four new activities are:

Process Chemistry - A process chemistry program will be initiated to help solve chemical and physicochemical problems related to energy production at geothermal power plants. Initial studies under the direction of Lawrence Livermore National Laboratory will address 1) improved methods for H₂S abatement and 2) development of real-time, on-line chemical monitors of gas chemistry at The Geysers. The DOE program manager is Gladys Hooper (202) 586-1146.

Vibrations in Drill Strings - Several organizations will collaborate on

establishing design and operating parameters of polycrystalline diamond compact (PDC) drill bits. The purpose is to eliminate self-excited drill string vibration, known as chatter, that can damage the string as well as the rig. The University of Southwestern Louisiana will continue its preliminary studies of this phenomenon with financial support from several bit manufacturers. Unocal and DOE will also contribute to Sandia's PDC bit program that aims to improve penetration rates in hard rock. The DOE program manager is Paul Grabowski (202) 586-0468.

Metastable Turbine Expansion - Extended Operations - The objective of the program is to operate a binary plant at inlet conditions that increase levels of supersaturation in the expansion and corresponding levels of condensation in the exhaust. The task is a significant extension of the current turbine investigation at Mammoth Pacific's MP1-100 power plant in California. The DOE program manager is Ray LaSala (202) 586-4198.

Microseismic Fracture Mapping - The objective is to investigate the applicability of a microseismic fracture mapping methodology developed for oil and gas exploration in geothermal environments. Acquiring knowledge of fracture location and areal extent in geothermal reservoirs would greatly reduce the cost of exploration and development. The DOE program manager is Dr. Marshall Reed (202) 586-8076.

GEYSERS CORING PROJECT RESULTS PRESENTED

The Department of Energy's Office of Geothermal Technologies sponsored a one-day symposium to present the principal research results from the joint DOE-industry Geysers Coring Project. The symposium was held in Santa Rosa, California, and provided a forum for the scientific investigators to communicate their research findings directly to interested parties. Attendees included the steam field operators at The Geysers, representatives of all the major operating companies, and officials from the State of California.

In late 1994, nearly 800 feet (240 meters) of continuous core were recovered from the impermeable caprock into the uppermost steam reservoir. This joint coring project provided triple the amount of core retrieved from The Geysers during its 35-year history. Rock cores are necessary to identify some critical parameters of a geothermal system. A 30-member team of collaborating geoscientists has been conducting detailed research on the core in the two years since its retrieval. New information was presented on reservoir porosity, permeability, and current fluid saturation. Knowledge of these variables is critical to the operating companies for improving forecasts of steam supply and energy recovery well into the 21st century. Such information is also useful when designing water-injection strategies to enhance future steam production and for optimizing resource management plans.

Industry and DOE scientists applied a number of new technologies to examine the core. Unocal used nuclear magnetic resonance imaging (MRI) to measure the minuscule quantities of water in the microscopic pores of the rock. The Lawrence Livermore Laboratory and

Stanford University used two different types of computer tomographic x-ray scanning (CT-Scan) to evaluate water movement within the core. The University of Utah used digital television scanners on microscopes to map 3-dimensional density variations of open pore space in the rock. Many of these successful techniques were custom-designed for this project.

GEOHERMAL ENERGY INTRODUCED TO WORLD RENEWABLE ENERGY CONGRESS

For the first time, the World Renewable Energy Congress included geothermal energy on its agenda as it met in Denver from June 16 through 21, 1996. The Office of Geothermal Technologies arranged a session on geothermal energy that featured nine papers by industry representatives. The main focus of the session was on small, modular, mobile power units for off - grid or minigrid applications in remote areas of developing countries. The advantages of geothermal direct use for crop drying, agricultural and industrial process heat, and space conditioning were also emphasized. The executive director of the Geothermal Education Office (GEO) also spoke on an education and training panel, describing GEO's highly successful approach to introducing geology and geothermal energy into primary and secondary school science curricula.

The Office of Geothermal Technologies mounted a large display in the exhibit hall and distributed literature. The Geothermal Resources Council, the Geothermal Energy Association, and the Geothermal Heat Pump Consortium also presented exhibits that attracted a great deal of attention.

During the wrap-up session, the Congress

convener acknowledged the contribution made by the geothermal community and pledged that geothermal would henceforth be included in future World Renewable Energy Congresses. Despite some expressions from solar energy fans that geothermal is not appropriately part of the "renewable" energy community, important steps were taken to bridge the gap between geothermal and other renewable energy technologies.

WORKSHOP TRANSFERS SLIMHOLE TECHNOLOGY

A workshop on Slimhole Drilling Technology was convened by Sandia National Laboratories and the Geothermal Resources Council in Reno, Nevada, on July 22-24. Over 70 participants and 26 speakers, including many from overseas, attended the workshop. The two days of presentations covered topics on slimhole exploration, slimhole drilling, reservoir evaluation using slimholes, the role of slimholes in project financing, slimhole-based systems for village power applications, and case studies.

On the third day of the workshop, a field trip was made to the Steamboat Hills Geothermal Field where a slimhole drilled in 1993 was flow tested to demonstrate production testing using a slimhole. Sandia set up a conventional James Tube and weir box to demonstrate the simple testing arrangement necessary for obtaining flow data. Advanced flowrate, temperature, and pressure transducers and a data acquisition system were also set up by Sandia to demonstrate a more sophisticated approach for conducting production tests. The advanced setup prompted significant interest from workshop participants. Following the flow

testing, a tour of the Steamboat Hills Geothermal Plant was hosted by the plant operator, Far West Capital.

Overall, the workshop appeared to be highly successful as a technology transfer mechanism and a place for industry representatives and researchers interested in slimhole technology to share ideas. A survey of workshop attendees indicated that industry is supportive of Sandia's past and ongoing work in this area; slimhole drilling and testing is a valuable exploration tool; and further research is needed. Participants also agreed that slimholes would continue to grow in their importance for exploration and production purposes.

GRC ADOPTS GOALS AND FIVE-YEAR PROGRAM

The Geothermal Resources Council (GRC) Board of Directors adopted a program plan that will serve as a guide to what specific programs, operations, and policies will be pursued in the next five years. The GRC board made special mention of the transition faced by the geothermal industry due to a number of circumstances and emphasized capitalizing on the strong capabilities developed over the years to overcome the problems.

The prime purpose of the GRC is to provide information and educational services to the industry. It also provides services to its affiliate organizations, International Geothermal Association (IGA) and Geothermal Energy Association (GEA). The IGA operates as an umbrella organization for all the national geothermal associations throughout the world. The GEA is the industry's trade association and promotes geothermal energy as a clean, reliable, sustainable energy source.

Highlights of discussions and action items for the next five years include:

- Focus annual meetings on export and international topics, including sessions on business and other financial matters. An international conference will also be convened every four years.
- Concentrate workshops and seminars on financing, reservoir management and power production, the subjects of greatest current interest.
- Develop partnerships between governmental agencies in the developing countries and U.S. companies to assist in course offerings and expenses.
- Promote joint meetings with the other industry associations to develop coalitions that promote greater geothermal development and broaden the scope of activities for GRC members.
- Develop relationships with key geothermal representatives in the Lesser Developed Countries (LDC) and recruit them for corporate membership. Make an appealing and appropriate case to use lending institution training funds to pay for such memberships.
- Coordinate with the IGA and GEA to develop joint working programs that avoid duplication of effort.
- Create a multifaceted homepage and list the GRC library on the Internet.
- Solicit new corporate memberships, particularly among vendors working domestically and internationally who indirectly take advantage of the GRCs programs, but are not helping to support the organization.

NEVADA BEGINS GEOTHERMAL DATABASE

The Nevada Bureau of Mines and Geology (NBMG) has begun a project to build a database of Nevada geothermal temperature-gradient drill hole information. NBMG is interested in obtaining any information on gradient- or slim-holes in Nevada. One purpose of the project is to preserve existing industry data that were collected during the 1970s and early 1980s and to make them readily available to future geothermal explorationists. This effort is being funded by the Department of Energy.

NBMG would like to obtain any files, maps, temperature logs, etc. related to geothermal drilling in Nevada. It is also interested in partial information on proprietary data, so that a complete Nevada database can list the present owner of such data. Such a listing should further the sharing of information and thus prevent needless recollection. Information on the location of gradient drill holes is of particular importance. The information will be entered into a database and made available for interactive search on a Geographic Information System such as ArcView.

If anyone is aware of data that might be available contact Larry Garside or Daphne D. La Pointe at NBMG. E-mail: lgarside@nbmg.unr.edu or dlapoint@nbmg.unr.edu.

Source: GRC Bulletin 3/96

PORTLAND HOSTS ANNUAL SCIENCE TEACHERS GEOTHERMAL WORKSHOP

The Geothermal Education Office (GEO) held its annual Teachers Workshop in conjunction with the Geothermal Resources Council's 1996 annual meeting in Portland, Oregon. The GEO is a non-profit organization led by Marilyn Nemzer. It is supported by the Office of Geothermal Technologies, to educate students and teachers on the merits of geothermal and other renewable energy resources.

About 100 teachers (and some advanced level students) from Oregon and Washington attended the one-day workshop. Speakers included Dr. Allan Jelacic, director of the Office of Geothermal Technologies and Dr. Phillip (Mike) Wright, president of the Geothermal Energy Association. Attendees had the opportunity to visit the GRC's exhibit and poster areas where goods and services used by the geothermal community were on display. The Pacific Northwest Geothermal Energy curriculum (developed by GEO), as well as many other GEO and GEO/GRC posters, videos, and publications were distributed to attendees.

THIRD INTERNATIONAL HDR FORUM DRAWS WORLDWIDE INTEREST

The Third International Hot Dry Rock Forum was held in Santa Fe, New Mexico, on May 13-16, 1996. The forum brought together 92 interested parties from government, academia, and private industry. The worldwide interest in geothermal hot dry

rock was reflected in the diversity of attendees, including 41 participants from the United States, 26 from Japan, 23 from Europe, one from Australia, and one from Armenia. There were over sixty presentations reviewing the major hot dry rock programs and the nascent hot dry rock work in developing countries.

The Forum highlighted information on worldwide progress in developing clean renewable energy from geothermal hot dry rock resources. This forum built on earlier ones held in Germany (May 1991) and Japan (November 1993). It provided a venue for discussions on the future direction of hot dry rock technology, and set the stage for a number of international cooperative efforts to help bring the technology to commercial fruition. The Fourth forum is tentatively scheduled for 1997 in France.

GEOTHERMAL ABSTRACTS TO BE AVAILABLE ELECTRONICALLY

The Department of Energy's Office of Energy Efficiency and Renewable Energy, in conjunction with the Office of Scientific and Technical Information (OSTI) has announced a new service designed to provide electronic access to abstracts of *Geothermal Energy* (GET). Beginning in March 1997, this Current Awareness Publication (CAP) will be available electronically, but no longer available in the previous paper format. This new service can be accessed on the World Wide Web (WWW) at:

<http://www.doe.gov/get/gethome.html>

In addition, interested parties can also elect to receive a listing of the titles from the above CAP processed by OSTI during the preceding two months. The listing can be

received by regular mail, e-mail, or fax at no cost. To use one of these options, your preferred choice must be indicated to OSTI.

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☐ Yes: I would like to receive a free listing.
(Please select one delivery option)
☐ E-mail (give address):

☐ Fax (give fax number):

☐ Paper (give mailing address):

☐ No: I do not want to receive a free listing.

For those who do not have Internet access, the abstract(s) can be ordered free of charge by calling 1-888-883-3859. Or send E-mail to: reports@adonis.osti.gov

The OSTI mail address is: P.O. Box 62, Oak Ridge, TN 37831

IMPROVED GHPs UNVEILED AT IGSHPA MEETING

Several improvements in geothermal heat pump technology were announced at the annual International Ground Source Heat Pump Association (IGSHPA) meeting held in San Antonio, Texas. The meeting was held in September 15-18, 1996, and attracted over 300 participants. Over 175 leading researchers, manufacturers, trainers, and utility representatives attended technical sessions, up from less than 100 two years ago. On September 17, a two-hour segment of the meeting was seen by thousands via a live national teleconference.

ClimateMaster announced a new and simpler GHP system, the Paradigm, to capture the retrofit market and save up to \$1,000 per house. Paradigm, designed for outdoor installation, eliminates the need for ripping apart existing heating and/or cooling devices and upgrading electrical connections. ClimateMaster's Dan Ellis estimates that Paradigm trims the cost of a complete retrofit geothermal installation by 20 to 30 percent.

Another highlight introduced was an advanced grouting method which improves thermal conductivities and reduces wellbore depths by up to 25 percent.

Discussions were also held on cost-cutting and marketing issues. These focussed on Sandia's drilling cost model and Cinergy's System GT. The former is designed to identify technology development opportunities and assist drillers in cutting costs while the latter is a marketing success story that resulted in sales of over 20,000 GHPs through a licensing arrangement with other utilities.

Associated Electric Cooperative, Inc. received the industry's first "10,000 Club Award" for their leadership in installing over 10,000 GHPs in their service area. Associated Electric has about 500,000 meters.

Lew Pratsch of DOE's Office of Geothermal Technologies received the IGSHPA's E.B. Penwood Award for Outstanding contributions to the Geothermal/Ground Source Heat Pump Industry.

GEO-HEAT CENTER REPORTS WILL HELP NEW GHP USERS

Geothermal space heating and greenhouse applications head the list in number of

requests for information and technical assistance forwarded to the Geo-Heat Center. In light of this fact, the center is planning to introduce new publications to broaden the information base for homeowners and greenhouse operators.

The greenhouse information package is designed for those with little or no experience with direct use geothermal applications and will cover issues beyond design and selection criteria, including:

- Selection and costs for greenhouse structures
- Temperature requirements for greenhouse crops
- Equipment vendors
- Heating requirements
- Heating equipment selection spreadsheet
- Greenhouse crop value information (where available)
- Customized geothermal resource information.

The Geothermal Heat Pump Document for Homeowners will expand on the publications currently available that focus on promoting GHPs rather than addressing specific technical issues. It will compile into one document information most often requested by homeowners exploring the possibility of using a geothermal heat pump. The various technical configurations (i.e., groundwater vs. ground coupled, vertical vs. horizontal ground loops, hydronic heating systems, etc.) will be addressed. The advantages and disadvantages, comparison with conventional systems, certified equipment, cost of purchasing and installing, what to look for in a dealer and/or contractor, and other useful information with their sources will also be included in the document.

OTHER SOURCES OF GEOTHERMAL INFORMATION

Some additional sources of information are listed here.

- **Geothermal Resources Council Bulletin**, Monthly publication of the GRC, P.O. Box 1350, Davis, California 95617-1350.
- **Geothermal Resources Council Transactions**, Proceedings of the GRC Annual Meetings. Same address as above.
- **Stanford University Annual Workshop on Geothermal Reservoir Engineering**, Stanford Geothermal Program, Department of Petroleum Engineering, Stanford University, Stanford, California 94305.
- **Proceeding of the Annual Geothermal Program Review**, Office of Geothermal Technologies, U.S. Department of Energy. Available from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161.
- **Federal Geothermal Research Program Update**, Office of Geothermal Technologies, U.S. Department of Energy. Available for Fiscal Years 1994, 1995, 1996.
- **Geo-Heat Center Quarterly Bulletin**, Oregon Institute of Technology, Klamath Falls, Oregon 97601-8801.

GEOTHERMAL POWER PLANT TABLES

The following tables present data on U.S. geothermal power generation facilities. The facilities listed are operational, except where footnoted otherwise, or where the year on line indicates the facility is planned. The information was assembled from published sources and direct contact with industry spokespersons. It is believed to be accurate as of the end of 1996.

Key to abbreviations used in power plant tables:

Companies

GDA	Geothermal Development Associates
HL	Honey Lake Power Company
OESI	OESI Power Corporation

Plant Cycle Type

DS	Dry Steam
DF	Dual Flash
SF	Single Flash
B	Binary

Utilities

BPA	Bonneville Power Administration
CDWR	California Department of Water Resources
HELCO	Hawaii Electric Light Co.
IID	Imperial Irrigation District
LADWP	Los Angeles Department of Water and Power
NCPA	Northern California Power Agency
PG&E	Pacific Gas and Electric Co.
PP&L	Pacific Power and Light Co.
PSPETL	Puget Sound Power Et Light Co.
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric Co.
SPP	Sierra Pacific Power Co.
SMUD	Sacramento Municipal Utility District
UPD	Utah Power Division of Pacific Corp.

U.S. GEOTHERMAL ELECTRIC POWER PLANTS: DRY STEAM PLANTS AT THE GEYSERS

PLANT NAME	FIELD DEVELOPER	PLANT OWNER	UTILITY	RATED CAPACITY (MW)	YEAR ON LINE
PG&E Unit 1 ^a	UNOCAL	PG&E	PG&E	11	1960
PG&E Unit 2 ^a	"	"	"	13	1963
PG&E Unit 3 ^a	"	"	"	27	1967
PG&E Unit 4 ^a	"	"	"	27	1968
PG&E Unit 5	"	"	"	53	1971
PG&E Unit 6	"	"	"	53	1971
PG&E Unit 7	"	"	"	53	1972
PG&E Unit 8	"	"	"	53	1972
PG&E Unit 9	"	"	"	53	1973
PG&E Unit 10	"	"	"	53	1973
PG&E Unit 11	"	"	"	106	1975
PG&E Unit 12	"	"	"	106	1979
PG&E Unit 15 ^a	Geothermal Resources Int'l.	"	"	59	1979
PG&E Unit 13	Santa Rosa Geothermal Co. ^b	"	"	133	1980
PG&E Unit 14	UNOCAL	"	"	109	1980
PG&E Unit 17	UNOCAL	PG&E	PG&E	110	1982

^a Retired

^b Formed by Calpine Corp. and Freeport-McMoran as new owner of leases and steam supply operations; originally Aminoil properties

U.S. GEOTHERMAL ELECTRIC POWER PLANTS: DRY STEAM PLANTS AT THE GEYSERS

PLANT NAME	FIELD DEVELOPER	PLANT OWNER	UTILITY	RATED CAPACITY (MW)	YEAR ON LINE
PG&E Unit 18	UNOCAL	PG&E	PG&E	110	1983
SMUDGEON No. 1	Santa Rosa Geothermal Co. ^b	SMUD	SMUD	72	1983
NCPA No. 1 ^c	NCPA	NCPA	NCPA	110	1983
Santa Fe Geothermal I	Santa Fe Geothermal	Santa Fe Geothermal	PG&E	80	1984
Bottle Rock ^d		CDWR	CDWR	55	1984
NCPA No. 2 ^c	NCPA	NCPA	NCPA	110	1985
PG&E Unit 16	Santa Rosa Geothermal Co. ^b	PG&E	PG&E	110	1985
PG&E Unit 20	UNOCAL	PG&E	PG&E	110	1985
Cold Water Creek ^d	Cold Water Creek Operating Co.	CCPA ^e	CCPA ^e	124	1988
Bear Canyon Creek	Santa Rosa Geothermal Co. ^f	Santa Rosa ^f	PG&E	22	1988
West Ford Flat	Santa Rosa Geothermal Co. ^f	Santa Rosa	PG&E	29	1988
Joseph W. Aidlin Power Plant	Geothermal Energy Partners ^g	Geothermal Energy Partners/Cloverdale Geothermal Partners ^h	PG&E	20	1989

^c Originally NCPA Nos. 2 and 3

^d Closed

^e Plant ownership divided among Sacramento Municipal Utility District (SMUD), Modesto Irrigation District (MID), and the City of Santa Clara

^f The new partnership of Calpine Corp. and Freeport-McMoRan owns both field and power plant operations; originally Geysers Geothermal properties

^g A subsidiary of Mission Power is general partner

^h Calpine Corp. and Metlife Capital Corp. (affiliate of Metropolitan Life Ins. Co.)

U.S. GEOTHERMAL ELECTRIC POWER PLANTS: HOT WATER PLANTS

LOCATION (State and Site)	PLANT NAME	TYPE	FIELD DEVELOPER	PLANT OWNER	UTILITY	RATED CAPACITY (MW)	YEAR ON LINE
<u>CALIFORNIA</u>							
Coso Hot Springs ^a	Navy 1, Units 1, 2, & 3	DF	CalEnergy	CalEnergy	SCE	80	1987- 1988
	BLM East (Units 1 & 2)	DF	CalEnergy	CalEnergy	SCE	48	1988
	BLM West	DF	CalEnergy	CalEnergy	SCE	28	1989
	Navy 2, Units 4, 5, & 6	DF	CalEnergy	CalEnergy	SCE	80	1989
East Mesa	GEM I (formerly B.C. McCabe)	B	GEO Operator/ Mission ^{b,c}	GEO/Mission ^c	SCE	12.5 ^d	1980
	Ormesa I	B	OESI	OESI	SCE	24	1986
	Ormesa II	B	OESI/Harbert Int'l	OESI/Harbert	SCE	17	1988
	Ormesa IE	B	OESI	OESI	SCE	8	1988
	Ormesa IH	B	OESI	OESI/Harbert	SCE	6	1989
	GEM 2	DF	GEO/Mission ^c	GEO/Mission ^c	SCE	37	1989

^a Various venture partners are involved in all CalEnergy Coso plants

^b Magma Power original owner

^c Mission Energy, a subsidiary of SCE

^d Enlarged from 10 MWe

U.S. GEOTHERMAL ELECTRIC POWER PLANTS: HOT WATER PLANTS

LOCATION (State and Site)	PLANT NAME	TYPE	FIELD DEVELOPER	PLANT OWNER	UTILITY	RATED CAPACITY (MW)	YEAR ON LINE
Glass Mountain	BPA Pilot II ^o	DF	Calpine	Trans-Pacific	BPA	30	1998 (est.)
Heber	Heber Dual Flash Power Plant	DF	Heber Geothermal Co.	ERC Int'l ^f	SCE	47	1985
	Heber Binary Project ^g	B	Chevron	SDG&E	SDG&E	45	1985
	Second Imperial	B	Ogden Corporation	Ogden Corporation	SCE	37	1993
Mono-Long Valley	Mammoth Pacific (MP) Unit I	B	Pacific Energy ^h	Pacific Energy /Constellation	SCE	7	1984
	MP Unit II	B	Pacific Energy	Pacific Energy /Constellation	SCE	10	1990
	MP Unit III	B	Pacific Energy	Pacific Energy /Constellation	SCE	10	1998 (est.)
	PLES Unit I	B	Pacific Energy	Pacific Energy /Constellation	SCE	10	1990
Salton Sea	Salton Sea Unit 1 ⁱ	SF	CalEnergy	CalEnergy	SCE	10	1982
	Salton Sea Unit 2 ⁱ	SF	CalEnergy	CalEnergy	SCE	18	1990
	Vulcan	DF	CalEnergy/Mission ^o	CalEnergy/Mission ^o	SCE	30	1985

^o Bonneville Power Administration Geothermal Pilot Project

^f Partnership of Dravo Corp. and Centennial Energy original owner

^g Demonstration plant supported by the U.S. Department of Energy; retired

^h Subsidiary of Pacific Enterprises

ⁱ Formerly developed by Unocal

U.S. GEOTHERMAL ELECTRIC POWER PLANTS: HOT WATER PLANTS

LOCATION (State and Site)	PLANT NAME	TYPE	FIELD DEVELOPER	PLANT OWNER	UTILITY	RATED CAPACITY (MW)	YEAR ON LINE
Salton Sea (Cont'd)	Del Ranch	DF	CalEnergy/Mission ^o	CalEnergy/Mission ^o	SCE	34	1988
	Elmore I	DF	CalEnergy/Mission ^o	CalEnergy/Mission ^o	SCE	34	1988
	Leathers I	DF	CalEnergy/Mission ^o	CalEnergy/Mission ^o	SCE	34	1989
	Salton Sea Unit 3	DF	CalEnergy	CalEnergy	SCE	48	1989
	Salton Sea Unit 4 ^j	DF	CalEnergy	CalEnergy	SCE	40	1996
Wendel-Amedee	Wineagle Project	B	Wineagle Developers	Wineagle Developers	PG&E	.7	1985
	Amedee Geothermal	B	Trans-Pacific Geothermal Inc. (TPG)/U.S. Energy Corp.	TPG/U.S.	PG&E	2	1988
	Honey Lake ^k	B	GeoProducts Corp.	HL Power Co.	PG&E	30	1988
<u>HAWAII</u>							
Puna	Puna I	SF/B	Puna Geo Venture ^l	Puna Geo Venture	HELCO	30	1993
	Puna II ^m	SF/B	Constellation	Constellation	HELCO	20	1999 (est.)
<u>NEVADA</u>							
Beowawe	Beowawe	DF	CalEnergy	CalEnergy	SCE	15	1985

^j A renegotiated power purchase agreement combined the Salton Sea I expansion and Fish Lake projects.

^k A hybrid plant using wood waste and geothermal heat; geothermal fluid used only to preheat boiler feedwater

^l Partnership between OESI and Constellation

^m Constellation is negotiating with HELCO for additional power purchase agreement

U.S. GEOTHERMAL ELECTRIC POWER PLANTS: HOT WATER PLANTS

LOCATION (State and Site)	PLANT NAME	TYPE	FIELD DEVELOPER	PLANT OWNER	UTILITY	RATED CAPACITY (MW)	YEAR ON LINE
Brady-Hazen	Desert Peak	DF	CalEnergy	CalEnergy	SPP	9	1985
	Brady Hot Springs I	DF	Brady Power Partners	Brady Power Partners	SPP	20	1992
Dixie Valley	Oxbow	DF	Oxbow Geothermal	Oxbow	SCE	50	1988
San Emidio Desert	Empire Geothermal	B	OESI	Empire Geothermal	SPP	3	1987
Steamboat Springs	Steamboat Geothermal I	B	Geothermal Development Assoc.	Far West Electric Energy Fund, Ltd.	SPP	6.8	1986
	Steamboat Geo IA	B	OESI/GDA	Far West	SPP	1.2	1989
	Yankee/Caithness	SF	Caithness/Sequa	Caithness/Sequa	SPP	12	1988
	Steamboat 2	B	Steamboat Development	Steamboat Development	SPP	12	1992
	Steamboat 3	B	Steamboat Development	Steamboat Development	SPP	12	1993
Stillwater/Soda Lake	Soda Lake I	B	Chevron	Institutional Investors	SPP	2.7	1987
	Stillwater Geothermal I Project	B	OESI	OESI/Constellation Development/Chrysler Capital	SPP	13	1989
	Soda Lake II	B	Amor	OESI	SPP	13	1990
Wabuska	Wabuska	B	Tad's Enterprises	Tad's Enterprises	SPP	1.5	1984

U.S. GEOTHERMAL ELECTRIC POWER PLANTS: HOT WATER PLANTS

LOCATION (State and Site)	PLANT NAME	TYPE	FIELD DEVELOPER	PLANT OWNER	UTILITY	RATED CAPACITY (MW)	YEAR ON LINE
UTAH							
Roosevelt Hot Springs	Blundell I	SF	CalEnergy Co. (originally Phillips; subsequently Chevron)	Utah Power Div. (UPD) of PacifiCorp	UPD	20	1984
Cove Fort-Sulphurdale	Cove Fort Geothermal No. I	B	Mother Earth	City of Provo	Utah Municipal Power Agency	2	1985
	Cove Fort Steam Plant	DS	Mother Earth	City of Provo	Provo Power Co.	2	1988
	Cove Fort Steam No. 2	DS	Mother Earth	City of Provo	Provo Power Co.	7	1989

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